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Ensuring that U.S. Engineers Remain Globally Competitive

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Interactive Qualifying Project-
Final Report
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"Engineering is the profession in which a knowledge of the mathematical and natural sciences, gained by study, experience, and practice, is applied with judgment to develop ways to utilize, economically, the materials and forces of nature for the benefit of mankind"

-ABET

ABSTRACT

The goal of this project was to analyze engineering education in America from the perspective of education, jobs, technology, and politics in order to determine where America stands with respect to other nations. The University of Tokyo, Indian Institute of Technology Delhi, University College London, Technical University of Münich, Massachusetts Institute of Technology, and Worcester Polytechnic Institute were analyzed to determine student demographics and engineering curricula. The nations of China, India, Germany, the United Kingdom, and Japan were selected for comparison against the United States as nations which are either up-and-coming in terms of global engineering or nations which already have a strong foundation in engineering and technology. The factors of job creation are considered with an eye for the science and engineering sector and the impact of technology on engineering and society as a whole is considered. The project concludes that, among other things, universities should endeavor to increase diversity in its student body and explore partnerships with businesses and the government. Nationally, the project recommends that more projects like Project Lead the Way, aimed at K-12 students, are developed. Furthermore, the project recommends that the nation changes its process of obtaining a visa to make it easier for foreign students pursuing STEM fields.

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EXECUTIVE SUMMARY

This project aims to analyze engineering education in America and make suggestions on how to keep the nation globally competitive. The specific areas of education, technology, jobs, and politics were considered in the context of keeping America globally competitive in order to make suggestions to universities and the nation as a whole.

To look at engineering education throughout the world, the University of Tokyo, the Indian Institute of Technology Delhi, the Technical University of Münich, the University College London, the Massachusetts Institute of Technology, and Worcester Polytechnic Institute were selected for research based on their rankings on the 2012 QS World University Ranking. Five specific majors which ranked in the Forbes 15 Most Valuable Majors (Fig. 1.1), selected for their modern day relevance, were focused on during the research: biological engineering, civil engineering, electrical engineering, mechanical engineering, and software and systems engineering. Data regarding the diversity of the student bodies at these universities reveals, for the most part, a striking lack of diversity. With the exception of MIT, the majority of students attending these universities have ethnic backgrounds native to the region in which the school is located. A gender gap is also apparent in the number of male to female students, with the exception of UCL, especially in WPI (Fig. 4.9). In all of the universities considered, engineering programs were by far the largest degree programs pursued by students, except in UCL, where it was the fourth most pursued set of majors. It is determined that a more rigorous admissions process paired with new, engineering-based metrics for measuring students would result in a more competent group of students. Once accepted to schools, students should be provided with greater guidance in the selection of their majors to ensure that they are selecting a major that is something they will excel in and enjoy. Furthermore, diversity must be pursued in universities in order to give their engineering students a broader perspective from which they can approach problems while keeping the ideals of other cultures in mind. Finally, although enrollment in engineering programs is on the rise, measures should be taken to ensure that this trend continues.

The causes of job creation in the United States are researched through discussing the effect that innovation has on the economy. By opening the lines of communication between universities, industries, and governments, partnerships that help nurture innovative ideas can be

formed in local regions across cities and in states. These partnership ‘clusters’ will also promote job creation by adding more businesses to a region and increasing the overall economy of that region. The case of the GlobalFoundries nano-manufacturing plant in Albany, NY is studied to show the positive effects a cluster can have on a region. It is recommended to universities, industries, and governments around the United States to create these innovation clusters in high-tech industries so that the jobs of the future will be here in America.

The effects of technology on society are analyzed, especially with respect to the impact of technology on the history of America. Several globally well-known research institutes, including MIT Lincoln Laboratory, the University of California Berkley, and the University of Cambridge are examined to determine how their funding is spent and where their personnel are concentrated in. This portion of the research draws conclusions regarding the need for increased investment by the government in the development of technology and the need to produce high-quality engineers.

The political portion of the project analyzes China, Japan, India, Germany, and the United Kingdom. Presently, developed nations, which include America, Germany, Japan, and the UK, spend roughly 2.5% of their GDP on R&D every year. Japan spends more at nearly 3.5%, and the UK spends less, at 1.8%. India spends 0.8% on R&D and China spends 1.8%, though these numbers are rising in both countries. In all of the nations, industry makes a considerable impact on R&D spending, and higher percentages are associated with greater industry involvement. All of the nations have adopted a variety of policies regarding science and technology to stimulate growth in these sectors, though the most effective policies appear to offer more funding to domestic research facilities and incentives to industry. Although the school systems of these nations are varied, each one produces a significant amount of degrees in the STEM fields. Numbers of students studying these majors in China and India are on the rise. The section concludes with recommendations that the United States should increase its spending on R&D and generate ways to increase its pool of STEM talent, especially through reliance on foreign students who come to America to study. It also proposes that the nation adopts plans for its S&T pursuits that cover five year periods in order to give the nation direction.

The project draws its final conclusions regarding engineering education at both the university level and the national level. For universities, the group recommends that universities increase their partnerships with businesses and the government; increase the diversity of their student bodies; keep their engineering curricula up-to-date; design a more thorough admissions process for prospective students, and; provide guidance for students regarding the selection of their majors. At the national level, the group makes recommendations for the American government to create more STEM education programs at the K-12 level; to make it easier for foreign students studying in America to obtain a visa, and; to increase funding for universities and research projects in general.

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1.0 INTRODUCTION

In the 25 years after 1970, federal funding for the research in the physical sciences, as a fraction of GDP, fell by 54%. Engineering funding fell 51% over the same period.[1] With decreases in funding as severe as these, it is only natural to wonder where the United States stands with respect to the rest of the world in the engineering and technology sectors. With other nations such as China growing at a faster pace, is the nation falling behind or are other nations simply catching up? Furthermore, if the US is indeed falling behind, what improvements can be made to remedy the situation and help to ensure that the country remains competitive in a world that is becoming progressively more globalized?

With that question in mind, the United States has been host to many of the world's greatest achievements in technology. From Alexander Graham Bell and the telephone patent to Thomas Edison and his incandescent lamp, Henry Ford and the Model T, and even the researchers at Bell Labs for their work on computers and UNIX; all of these are well known breakthroughs which have revolutionized the world and continue to affect modern day life. Perhaps one of the greater advancements came from the American system of manufacturing: interchangeable parts and the highly mechanical process for manufacturing goods used around the world in many factories. Presently, science, technology, engineering, and math (STEM) professionals continue to make discoveries in their respective fields, but there are still some countries that seem to be lacking in the amount of technology that is available to them in comparison with the United States. Is there any particular reason for this discrepancy or is it just a result of developed nations seeing technological breakthroughs first?

The United States is currently one of the highest ranked countries in the area of engineering, based on a number of papers written and cited.[2] These ranks place the U.S. anywhere from fifth to first on such lists. Recently, Forbes reported the top fifteen college majors based on projected job growth; a third of those majors were in the area of engineering (Fig. 1.1).[3]

[1] N. Augustine, Is America Falling Off the Flat Earth?, National Academy of Sciences, National Academy of Engineering, Institute of Medicine, 2007; http://www.nap.edu/openbook.php
[2] http://www.interface.edu.pk/students/May-08/Best-Engineering-Universities.asp
[3] "15 Most Valuable College Majors". Forbs Magazine http://www.forbes.com/sites/jennagoudreau/2012/05/15/best-top-most-valuable-college-majors-degrees/

With the U.S. losing dominance in engineering will engineering positions continue to be filled by students graduating from American engineering programs or will students from other countries emerge and take the lead?

Figure 1.1

Rank	Major	Class	Starting Median Pay	Pro. Job Growth
No. 1	Biomedical Engineering	Engineering	53,800.00	61.7%
No. 2	Biochemistry	Science	41,700.00	30.8%
No. 3	Computer Science	Science	56,600.00	24.6%
No. 4	Software Engineering	Engineering	54,900.00	24.6%
No. 5	Environmental Engineering	Engineering	51,700.00	21.9%
No. 6	Civil Engineering	Engineering	53,100.00	19.4%
No. 7	Geology	Science	45,300.00	19.3%
No. 8	Management Info. Systems	Math	51,000.00	18.1%
No. 9	Petroleum Engineering	Engineering	97,900.00	17.0%
No. 10	Applied Mathematics	Math	52,600.00	16.7%
No. 11	Mathematics	Math	47,000.00	16.7%
No. 12	Construction Management	Engineering	50,200.00	16.6%
No. 13	Finance	Math	46,500.00	16.0%
No. 14	Physics	Science	49,800.00	14.2%
No. 15	Statistics	Math	49,000.00	14.1%

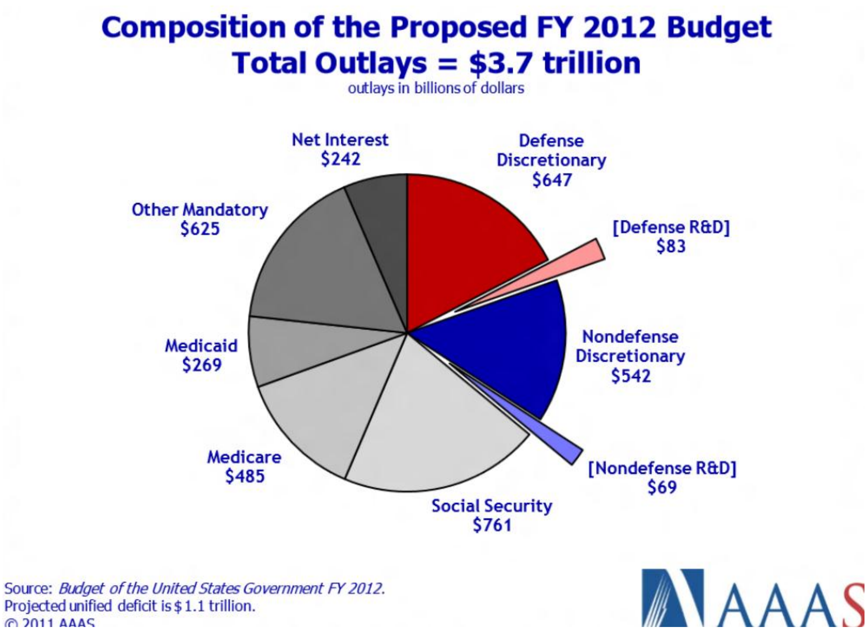
"15 Most Valuable Majors"

This figure shows the top 15 majors: engineering (green), science (red), and mathematics (orange).

With other nations catching up with the U.S. in terms of engineering education, it is important to consider the policies of these nations. The two primary areas of policy that would affect those sectors would be a country's educational and economic policies. In Germany, students are typically divided into three groups at a relatively young age, with each group having a different degree of academic rigor. Students who attend the German *Gymnasium* and complete the final exam qualify for attending a university.[4] Does such a division of students help generate a more capable set of engineers or is there no impact on the quality of engineers who graduate from a university?

Another country to look to is China. Starting in the early 90s, there was a major restructuring of the Chinese university system, which included the mergers of some universities and a drastic increase in funding for key campuses to generate "world class" facilities on par with the Ivy League schools of America. Has the allocation of more funds improved the quality of graduating engineers? China also provides an interesting comparison with regards to their economic policies. In 2011, the United States spent $69 billion on non-defense research and development, which accounts for roughly 1.85% of the total budget.[5]

Figure 1.2

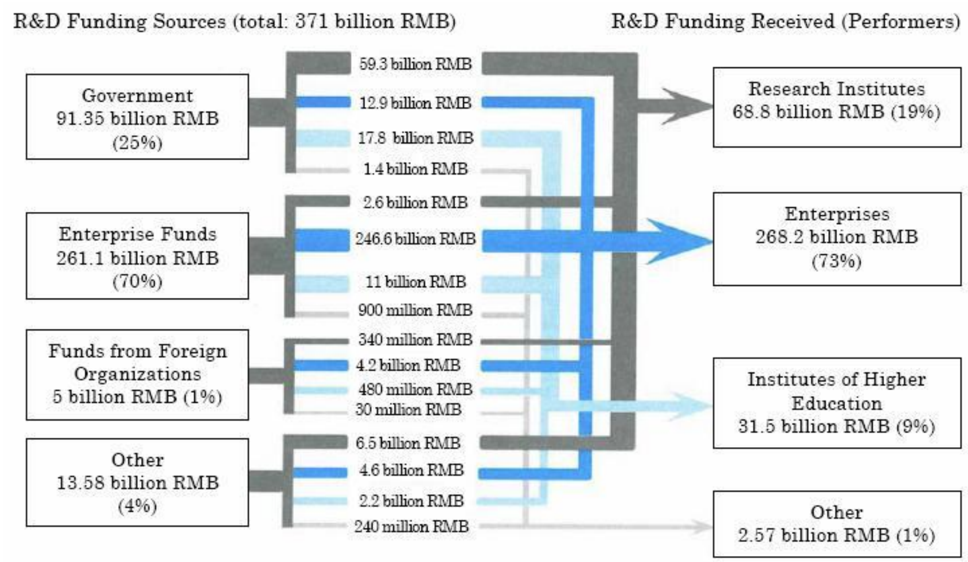


US FY2012 Budget

[4] Neue Horizonte by David Dollenmayer, Thomas Hansen
[5] http://www.ieeeusa.org/policy/cvd/2011/CVD2011-Budget-Slides.pdf

In 2011, China devoted nearly 4% of their total budget towards research and development.[6] Out of the $14 billion that China spent on R&D, $9.4 billion of that went to their own domestic R&D programs (Fig.1.3). Would such increased funding help to foster high-tech businesses and engineering projects?

Figure 1.3



R&D Funding Sources in China

Figure from: China's Program for Science and Technology Modernization: Implications for American Competitiveness. Springut, Micah; Schlaikjer, Stephen; Chen, David. January 2011.

1 Chinese Yuan (RMB) = 0.159 US dollar

One of the biggest concerns during an election year, especially in America's present economic state, is the topic of jobs, specifically creation and growth. These topics often receive a large amount of attention in both candidate debates and political ads. Each party has opposing plans on how to stimulate job growth and creation. Who really creates the jobs? The political debate essentially boils down to the issue of who is taxed and how much. By looking into the answer of this question, an understanding of the steps involved in creating jobs will be developed. Furthermore, a determination may be made as to who is filling the jobs that are being

[6] "15 Most Valuable College Majors". Forbes Magazine http://www.forbes.com/sites/jennagoudreau/2012/05/15/best-top-most-valuable-college-majors-degrees/

created. Through the review of case studies on businesses, it will be shown that demand, or the consumers, are the true job creators.[7] The money that the consumer spends is the driving force in determining whether businesses, big or small, will grow and expand or fail and give up.

[7] Jacobs, F. Robert., and Richard B. Chase. "Case: The Tao of Timbuk2." *Operations and Supply Chain Management*. 13th ed. New York: McGraw-Hill Irwin, 2010. 36-37.

2.0 BACKGROUND

This IQP will focus on the issues the U.S. faces trying to maintain its position as one of the most globally competitive engineering nations. The U.S. potentially faces problems in politics, education, jobs, and technology. Different eras of history have allowed the U.S. to grow significantly as a nation.

Many colleges have varying numbers of engineering degree programs, ranging anywhere from aerospace engineering all the way to textile engineering. With such a large number of programs available, this project will focus on five programs that the project members have chosen based on historical popularity and future need for engineers in those fields. The specific engineering degrees to be investigated are bio-engineering related (biotech, biomedical etc.), civil engineering, electrical engineering, mechanical engineering, and software and systems engineering.

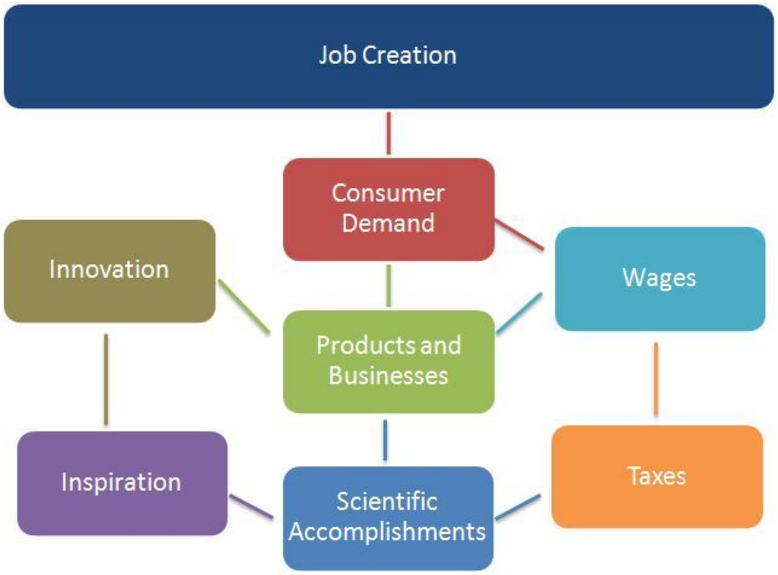
Looking globally, there are many countries other than the U.S. that have great engineering foundations. By analyzing the policies in effect of some of these countries, the project will hopefully gain some insight on the politics behind such rapid engineering and technological growth. These insights can then be applied to make suggestions with regards to U.S. policy in similar areas that may promote growth of the nation's domestic engineering and technology sectors.

The growth of engineering and technology within the United States would be a great relief to the sluggish economy by creating more and better jobs. In 2010, the National Science Foundation stated that 96% of jobs in the work force are disproportionately created by the 4% of the work force that are made up of scientists and engineers.[8]This is because these scientists and engineers are innovating new products and ideas that will be used by current or startup businesses to manufacture the product which then will be transported to stores who will have sales men and women selling to the customers whose demand will in turn require businesses to hire more employees. Yet the investment in engineering and technology alone is not the United

[8] National Science Board, Science and Engineering Indicators 2010. Arlington, VA: National Science Foundation (NSB 10-01); Figure 3-3.

States' panacea, there is a complex ecosystem of factors that play a role in the growth of jobs. In Figure 2.1 is the visual depiction of the factors involved in the web of job growth.

Figure 2.1



Web of Job Growth

This chart shows the various pieces involved in job creation and their interconnectivity.

These factors include: inspiration, innovation, scientific advances, products and businesses, consumer demand, job creation, wages, and taxes. With continued research on these factors, a conclusion will be made in Section 4.2 on their contribution to the job growth and continued prosperity of the United States.

With the purpose of realigning on the path to prosperity, the research of this project focuses on the causes for the slow growth in engineering in America compared to other countries, some of which seem to be growing faster. The group will look at how technology is critical to America's future and how engineering directly impacts the nation's competiveness. New technologies often lead to the creation of new businesses and jobs in healthcare, environmental protection, clean water and air, farming, transportation, communication, disaster mitigation, energy conservation, education, homeland security, etc. America must continue educating its children in order to develop a strong workforce of scientists and engineers, while continuing advancements in technology. This IQP group will put forth a plan to increase the quantity and quality of engineers in the United States by looking at historical trends and data from engineering schools around the world.

The United States has a relatively short historical timeline with respect to other nations. In less than 240 years, the U.S. has made significant contributions to science and technology. The primary time period that this project will focus on is the Post-Reconstruction era up through the beginning of the 21st century. The period after the Civil War saw great advances in electrical engineering and physics. Even to this day, many breakthroughs continue to be made in various engineering disciplines. By analyzing the past, predictions may be made as to whether or not these trends will continue.

2.1 ASSEMBLY LINE, 1870'S—1920'S

The period after the Civil War and at the tail end of the Industrial Revolution had brought huge growth to the domestic manufacturing industry. This era, starting with the reconstruction of the South, saw many great advances in science and technology. As an example, Thomas Edison, "The Wizard of Menlo Park", was one of the most distinguished inventors of the United States. He held over 1,000 patents, many of them for electrical technologies and motion pictures. Henry Ford's assembly line revolutionized manufacturing and brought about lower cost and more efficient manufacturing processes. Many of the early pioneers in science and technology were self-taught and studied many different disciplines in order to accomplish what they did. For example, Nikola Tesla was not only an electrical engineer, but also an inventor, mechanical engineer, physicist, and futurist. This period laid the groundwork for the next period of advancement.

2.2 PHYSICS, 1920'S—1960'S

Many of the engineering developments in the post-World War I era have had a significant impact on today's technology and have spurred many further developments. The Atanasoff-Berry computer, developed in 1937, was the first electronic digital computing device.[9] Its conception paved the way for more complicated computing devices. In the same year, a group of German engineers led by Hans von Ohain developed the first jet engine which continues to be significant

[9] Ralston, Anthony; Meek, Christopher, eds. (1976), Encyclopedia of Computer Science (second ed.), pp. 488–489, ISBN 0-88405-321-0

to this day. During World War II, the Manhattan Project was able to split an atom creating both the most powerful source of energy to date as well as the most dangerous weapon. Yet another achievement was the conception of the transistor in 1947 by John Bardeen and Walter Brattain at Bell Labs. The transistor is a component that is present in almost all of our electronic devices to this day, including computers. Although computers were a relatively new concept during the later stages of this period, the computer science field rapidly developed. This rapid progress would later give rise to the Information Age.

2.3 INTEGRATED CIRCUITS, 1960'S—PRESENT

The evolution of the transistor and the development of integrated circuits brought about high speed computing, miniaturization, and the application of digital technologies to an ever increasing array of products. More importantly, the capabilities of digital communication put the world on a trend of becoming highly globalized.

The education of scientists and engineers is another trend that saw change in this time period. A formal education seems to be the standard in order to gain comprehension for a highly specialized area of a certain field. On the other hand, there are some notable examples of people without formal education who have achieved great success in their specialized area. Dennis Ritchie, one of the most influential computer scientists of the modern era, graduated with degrees in physics and applied mathematics, yet had no formal training in computer science. These days, it is unlikely that a pioneer of a certain field would not have obtained a degree in that field. It is certainly possible for an individual to learn the required knowledge on their own, but proving that they have this knowledge to an employer would be difficult. By obtaining a degree, an employer can be certain that one is able to perform the tasks required to succeed in their field. On the other hand, some modern day technological pioneers, including Bill Gates, Steve Jobs, Mark Zuckerberg, and Dean Kamen dropped out of college, showing that although a formal education is not necessarily a primary component of success, the number of people who succeed without such an education are few in number.

2.4 SUMMARY

By examining the past, it can be seen that the scientific discoveries and technological advances made have always laid down the foundation for the U.S. to be a competitive nation on the global stage. Despite the current challenges of a divided political structure, lagging education, high unemployment and decreasing funding to science and technology, the U.S. is still able to maintain a leading position in engineering, thanks to the efforts of prior generations. This IQP will look more closely at the challenges being faced today and will determine what course of action needs to be taken by the U.S. to maintain its leadership role in science and engineering in the world.

3.0 METHODOLOGY

Two sets of goals were established for this project. The first were primary goals that give the project direction. The second were area of study goals that each member made to focus on their individual sections. Research has been defined to look at specific engineering college majors, as well as certain countries. Data was compiled from online articles, books, and journals. This data was then compared to and verified by data from sources such as the Bureau of Labor Statistics, the National Academy of Sciences, the National Academy of Engineers, the U.S. Census Bureau, and more. Only then were conclusions about the data drawn. Including research, conclusions, and presentations, the project spanning three terms culminated in March 2013 with a PowerPoint presentation and technical report.

3.1 GOALS

The primary goals are:

- To make suggestions to United States policy makers toward ensuring the continued leading status of the U.S. in engineering and technological fields, with specific attention to education and economic policy.
- To make predictions and draw attention to solutions for the future direction of engineering education on a national scale.
- To suggest to Worcester Polytechnic Institute ways to attract and retain students in engineering majors which are important for future success yet currently have low enrollment trends.

3.1.1 EDUCATION GOALS

Within the education area, the specific goals are:

- To look at the global trends in engineering majors,
- To look at techniques for educating engineers in the U.S. and globally,
- To see the trends in demographics of American engineers.

3.1.2 JOBS GOALS

The specific goals of the jobs area are:

- Determine how large numbers of engineering jobs can be created in the 21st century
- Discover the conditions that are necessary to create those jobs
    - Find out what the United States is doing to encourage job growth
    - What is being done in regional and local levels to create jobs
- Conclude on what results can be expected from successful implementation of this strategy

3.1.3 TECHNOLOGY GOALS

With respect to the technology area, specific goals include:

- Investigate differences between design and manufacturing jobs
    - Many design jobs are in the US, while manufacturing jobs are outsourced
- Look at different technological breakthroughs in history
    - See various causes and effects
- Compare different research universities
    - See where their funding comes from
    - Observe which schools focus more on technological research
- Investigate government involvement in technology research

3.1.1 POLITICAL GOALS

In the political area, the specific goals are:

- Examine the government structure of selected nations.
    - Look at the internal structure of governments, especially departments that relate to engineering and technology, and compare them to the US to look for efficiencies or inefficiencies in the bureaucratic systems that affect the development of those sectors.
- Evaluate the educational and economic policies of these nations.

    - Look at the policies that pertain specifically to engineering and technology and determine the success or failure of these policies to generate growth in those sectors.
- Determine political factors leading to engineering and technology sector growth.
    - By examining the various political structures that pertain to the growth of a country's engineering and technology sectors, successful strategies may be identified so that they may be applied to the United States.

3.2 SCOPE

A project of this size required clear boundaries within which the research was to be conducted. As previously mentioned, the project timeline spans across the post-Reconstruction era up through present day, as it is representative of a time frame where both globalization and innovation were rapidly increasing. Also bounding the project’s focus were constraints on the number of engineering majors and countries looked at during the group analysis.

3.2.1 EDUCATION CONSTRAINTS

This project will analyze five college majors:

- Biological Engineering
- Civil Engineering
- Electrical Engineering
- Mechanical Engineering
- Software and Systems Engineering

Although there are many college degree programs out there, there just isn’t enough time within the scope of this project to look at all of them. The programs that have been selected were picked based on their historical popularity, modern day relevance, and the projected need for engineers in those fields in the future. Three of the selected majors were in the 15 most valuable college majors, while the other two represent what can be considered as classical engineering programs.

3.2.2 COUNTRY CONSTRAINTS

Globally, there are many other countries than the U.S. that have great engineering foundations. This project will focus on five foreign countries:

- People's Republic of China (China)
- Federal Republic of Germany (Germany)
- Republic of India (India)
- Japan
- United Kingdom

Germany, the United Kingdom and Japan were selected as examples of countries that are well-developed, have standards of living comparable to that of the United States, and have robust engineering foundations. These countries will serve as a good comparison against the U.S. on a roughly equal footing. China and India, though still developing nations, are developing at an increasingly rapid pace. It was because of this development that these nations were selected. Both countries are seeing their technology and engineering sectors growing quickly.

3.3 RESEARCH METHODOLOGY

Group members were tasked with conducting in depth research in their given areas of study. Each member went about this in their own way. The group also consulted a number of scholarly reports regarding topics of relevant interest. The following sections outline the individual methodology of each member in his research.

3.3.1 EDUCATION

The first step in the research on engineering education was to choose specific engineering schools to look into. To pick the schools the group looked at the *2012 QS World University Rankings by Subject: Engineering and Technology*, which ranked schools based on academic reputation, employer reputation, faculty to student ratio, international faculty, international students, and citations per faculty.[10] Looking at all the schools and then dividing them into the countries they are located in, the group then picked one of the top schools from the specific countries that had been chosen: China, Japan, India, Germany, England, and the US.

The universities the group chose were the University of Hong Kong (KHU) in China; the University of Tokyo (Todai) in Japan; the Indian Institute of Technology Delhi (IITD) in India; the Technical University of Münich (TUM) in Germany; University College London (UCL) in England; and the Massachusetts Institute of Technology (MIT) and Worcester Polytechnic Institute (WPI) in the US. Once the schools were picked, the plan was to look at two schools at a time and find out a little bit of their history, their admissions processes, the demographics of enrolled students, the breakdown of enrollment in specific majors, and the job outlook for graduates.

When looking at each school, there were specific pieces of information that the group was looking for as far as hard data and numbers. The group was looking for enrollment statistics that included male and female enrollment percentages, foreign student enrollment by country or region, enrollment of various ethnic backgrounds, and enrollment in specific majors or faculties.

Most university webpages gave general 'at a glance' information that wasn't completely helpful. [11] To find the information that the group was looking for, the group had to dig deeper into webpages and sometimes look in places that were not completely obvious. All the data the group collected was put into pie graphs, bar graphs, or line graphs. Line graphs typically represent information that spans a length of time. The information that went into these graphs generally came from archived reports and took considerable time to analyze.

3.3.2 JOBS

The research methodology for the jobs portion of this report followed two tracks. Track one was to determine what the best and brightest minds were thinking was necessary for job creation in the 21st century. Track two was focused on who was actually executing a strategy, creating jobs and getting results. Relevant studies on STEM, innovation, job creation, small business, politics, K-12 education, engineering education, and the need for life-long learning for

[10] http://www.iu.qs.com/university-rankings/subject-tables/
[11] http://web.mit.edu/facts/faqs.html

engineers were reviewed. Current news articles and corporate and financial information were used to identify businesses and governments that were successfully creating jobs.

By conducting this research it should be possible to answer the following questions: 1) How is it possible to create large numbers of engineering jobs in the 21st century? 2) What are the conditions necessary for the creation of those jobs? 3) What is the United States as a nation, doing to set those conditions and encourage job creation? 4) What is being done on a regional or local level to create jobs? 5) What results can be expected from a successful execution of this strategy?

3.3.3 TECHNOLOGY

The main focus of the technological section of this project is on research institutions. The overarching question to be answered is "Are research institution worthwhile?" There are various universities that do their own private research, as well as those who are funded by the government/private sector companies to perform directed research. This project aims to show that these research institutions are very valuable to the United States as they have historically discovered life-changing technologies.

Another topic covered under technology is the idea of quantity vs. quality. As a nation, the United States has little to no control over our population in terms of numbers. The US simply cannot match the number of people living in Asian countries, China for example, However, the US can provide a good education to its students, developing them into quality engineers. While quantity is desirable for manufacturing jobs, conducted research has proven to be more successful when conducted by the highest quality engineers. This proves that quality is more important than quality when it comes to research.

To accomplish this research, several major United States research institutions were looked at. Specifically, research was conducted on the MIT Lincoln Laboratory (backed by the US Department of Defense) and Oak Ridge National Laboratory (backed by the US Department of Energy).

3.3.4 POLITICS

With regards to the chosen nations, the key areas identified for research were spending on science and technology, science policy, number of researchers in the nation, scientific output in terms of scientific articles, and science education.

Most of the resources consulted during the analysis of these nations were from reports put out by various international research institutes which analyzed the scientific capacity that these nations had. These reports often looked at hard statistics in the context of policies that the nations had implemented and evaluated their effectiveness based on that data. Data reported by the various government agencies of these nations was also consulted.

3.4 SCHEDULE

A timeline for the project, including a schedule that spans three terms and features milestones for progress, was developed:

- A-Term—Project Initiation :
  - Deliverables:
    - Introductory Research (15 Sept 12)
    - Background Research (22 Sept 12)
    - Proposal Rough Draft (28 Sept 12)
    - Proposal 2^{nd} Draft (6 Oct 12)
    - Presentation of Project (9 Oct 12)
    - Proposal Final Draft (12 Oct 12)
- B-Term—Project Research:
  - Deliverables:
    - Project Research (23 Oct 12—16 Nov 12)
    - Current Findings (20 Nov 12)
    - Continued Research (21 Nov 12—30 Nov 12)
    - Technical Report Work Completed Rough Draft (7 Dec 12)
    - Presentation of Work Completed (10 Dec 12)
    - Technical Report of Work Completed Final Draft (14 Dec 12)
- C-Term—Project Findings and Conclusions:

- Deliverables:
  - Conclusions on Research (10 Jan 13—25 Jan 13)
  - Letter of Suggestions to WPI Rough Draft (30 Jan 13)
  - Submit Letter of Suggestions (13 Feb 13)
  - Final Report Rough Draft (13 Feb 13)
  - Final Report (20 Feb 13)
  - Project Presentation (20 Feb 13)

4.0 INDIVIDUAL RESEARCH AND CONCLUSIONS

The following four sections present the findings of the group in the areas of education, jobs, technology, and politics.

4.1 EDUCATION

As previously mentioned, the universities that were researched for this report were: the University of Tokyo (Todai); the Indian Institute of Technology Delhi (IITD); the Technical University of Münich (TUM); University College London (UCL); the Massachusetts Institute of Technology (MIT) and Worcester Polytechnic Institute (WPI). The universities outside the United States are often depicted in a different light. This is because they are institutions which have been created solely for the advancement of learning whereas in the United States, we have universities for advanced learning, but we also consider social and recreational aspects of student life. Other universities may have lower relative tuitions or expenses, but do not fund programs such as Division I football teams, marching bands, et. al. These differences in social and recreational expenditures, although important to understanding the inner-workings of these universities, are not considered in this project. What was considered in this area of research was historical information, the admissions processes, and student demographics were among some of the topics looked at during the research. In the following sections, the research conducted regarding education is presented in further detail.

4.1.1 UNIVERSITY BACKGROUNDS

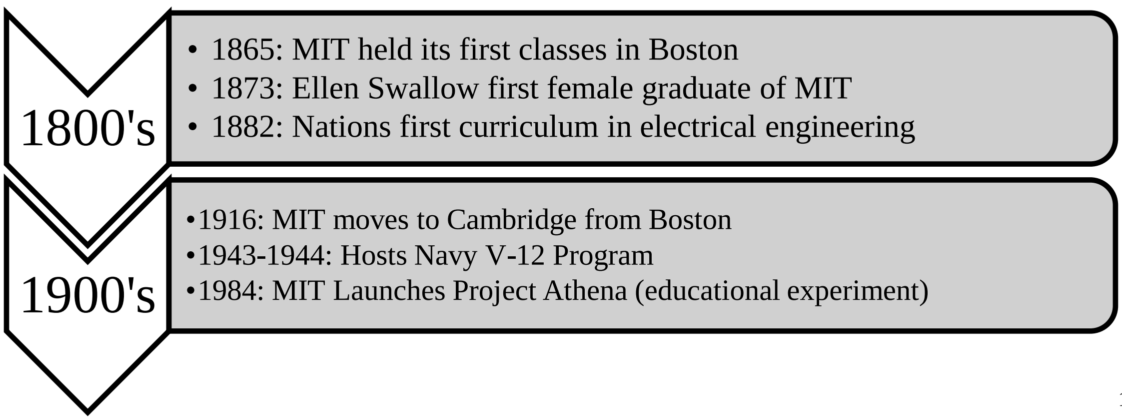
All of the universities that were selected rank in the Overall Top 400 and Top 400 Engineering and Technology schools globally, based on the *2012 QS World University Rankings.* These rankings "are based on data covering four key areas of concern for students: research, employability, teaching and internationalization."[12] Going into more detail, the rankings are also determined by six factors that have different weights that sum together to give an overall score. The following are the factors used and their overall weight: Academic reputation (40%); Employer reputation (10%); Faculty/student ratio (20%); Citations per faculty (20%);

[12] http://www.topuniversities.com/university-rankings/world-university-rankings/methodology-simple-overview-qs-world-university-rankin

International faculty ratio (5%); and international student ratio (5%).[13] Background information for each of the universities is provided in the following sections in order of their overall rank with the highest presented first.

4.1.1.1 MASSACHUSETTS INSTITUTE OF TECHNOLOGY (MIT)

The Massachusetts Institute of Technology (MIT) is located in Cambridge, Massachusetts and is ranked 1st both in overall ranking and in engineering and technology by the *2012 QS World University Rankings*.[14] MIT has a long history of excellence and has a mission to advance knowledge and educate students in science, technology, and other areas of scholarship that will best serve the nation and the world in the 21st century.[15] Below is a brief history of MIT from its foundation.



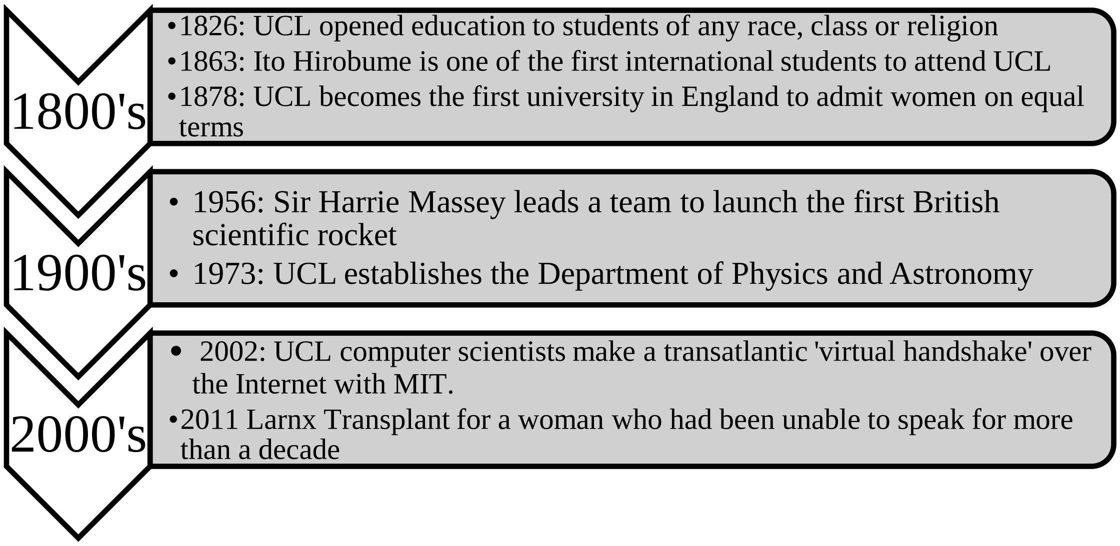
[16]

4.1.1.2 UNIVERSITY COLLEGE LONDON (UCL)

The University College London (UCL) is located in the heart of London. Teaching at this university is research-based and the school offers programs that reflect the latest research, which are taught by active researchers who are world-leaders in their fields.[17] This high caliber of

[13] http://www.topuniversities.com/university-rankings/world-university-rankings/methodology-simple-overview-qs-world-university-rankin
[14] http://www.topuniversities.com/institution/massachusetts-institute-technology-mit
[15] http://web.mit.edu/facts/mission.html
[16] http://libraries.mit.edu/archives/timeline/index.html
[17] http://www.topuniversities.com/institution/ucl-university-college-london

teaching has led to UCL ranking 4th overall and 44th in engineering and technology by the *2012 QS World University Rankings.*[18]

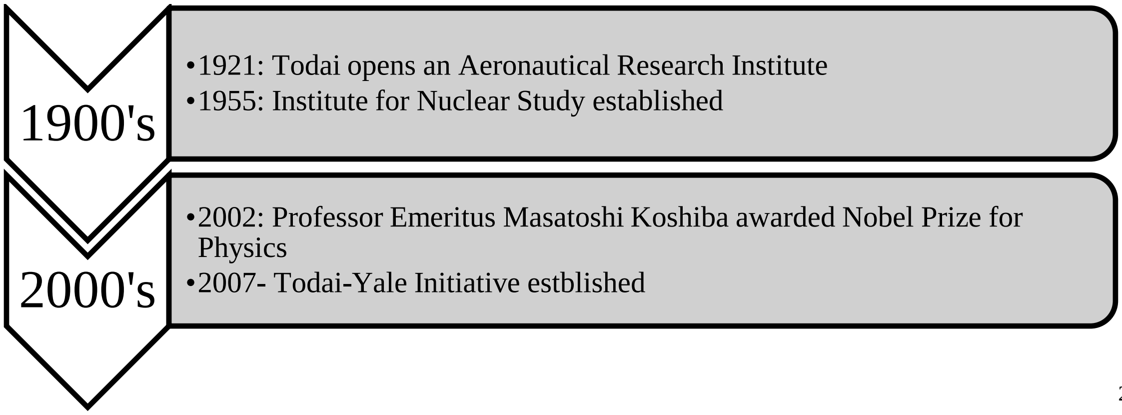


[19]

4.1.1.3 UNIVERSITY OF TOKYO (TODAI)

The University of Tokyo (Todai) is Japan's top university, a world-class center for research, and a vibrant academic community. This university ranks 30th overall and 7th in engineering and technology on the *2012 QS World University Ranking.*[20] Todai has nine 'academic pursuits', one of which is "goals of education". "The University of Tokyo will open its doors on all of its campuses to everyone with suitable qualifications and aptitude for learning. In each branch of higher learning, it will nurture people of leadership qualities who possess an international character and a pioneering spirit in addition to being equipped with expert knowledge, comprehension powers, insight, practical strengths and imagination. Toward this goal, The University of Tokyo will seek the highest standard of education in the world, all the while respecting the individuality of students and their right to learn."[21]

[18] http://www.topuniversities.com/institution/ucl-university-college-london
[19] http://www.ucl.ac.uk/about-ucl/
[20] http://www.u-tokyo.ac.jp/en/admissions-and-programs/undergraduate-students/admissions-process/sp-screening-test.html
[21] http://www.u-tokyo.ac.jp/gen02/b04_01_e.html

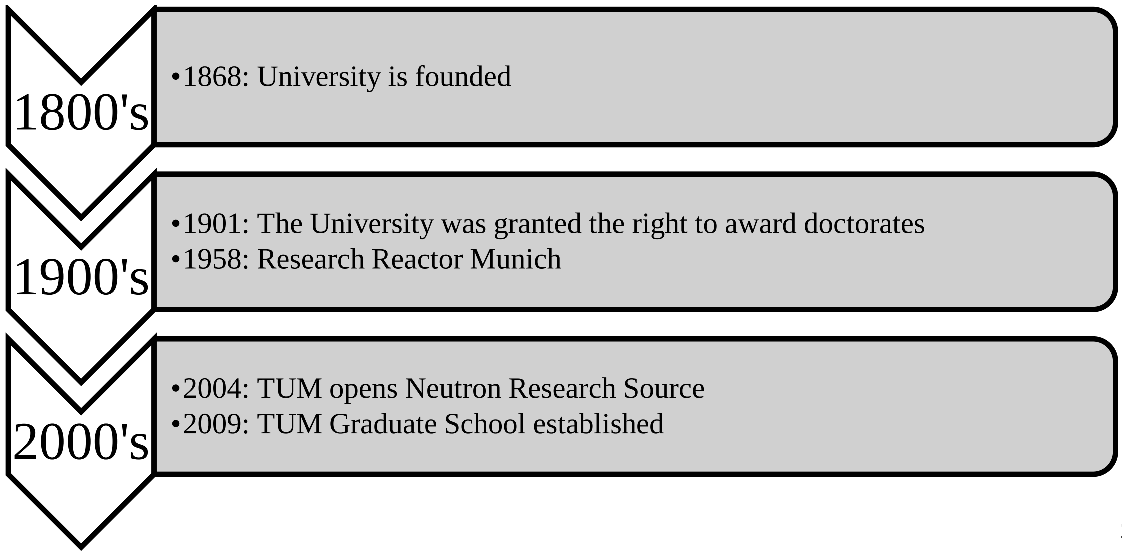


[22]

4.1.1.4 Technical University of Münich (TUM)

The Technical University of Münich (TUM) has campuses in Münich, Graching, and Weihenstephan. "TUM was founded to provide the state of Bavaria with a center of learning dedicated to the natural science. It has played a vital role in Europe's technological advancement and has the prestige of producing a number of Nobel Prize winners."[23] TUM has a wide range of areas of study including engineering, natural sciences, life and medical science, and economics, which helped them earn the rankings of 53rd overall and 21st in Engineering and Technology in the *2012 QS World University Rankings*.[24]

[22] http://www.u-tokyo.ac.jp/en/about/history.html
[23] http://www.tum.de/en/about-tum/leadership-and-university/geschichte/
[24] http://www.topuniversities.com/institution/technische-universitaet-muenchen



[25]

4.1.1.5 INDIAN INSTITUTE OF TECHNOLOGY DELHI (IITD)

The Indian Institute of Technology Delhi (IITD) is one of the seven Institutes of Technology created as centers of excellence for higher training, research and development in science, engineering and technology in India.[26] Although it is a relatively new university, having been established in 1961, it was ranked 212th overall on the *2012 QS World University Rankings* and ranked, more importantly to this report, 60th in Engineering and Technology by the same ranking source.[27] The vision statement guiding IITD is “To contribute to India and the World through excellence in scientific and technical education and research; to serve as a valuable resource for industry and society; and remain a source of pride for all Indians.”[28] This vision coupled with part of its mission; “To generate new knowledge by engaging in cutting-edge research and to promote academic growth by offering state of the art undergraduate, postgraduate and doctoral programs”[29] show the ambitions of this institute in engineering education.

[25] http://portal.mytum.de/tum/geschichte/index_html/document_view
[26] http://www.topuniversities.com/institution/indian-institute-technology-delhi-iitd
[27] http://www.topuniversities.com/institution/indian-institute-technology-delhi-iitd
[28] http://www.iitd.ac.in/content/vision-mission-values
[29] http://www.iitd.ac.in/content/vision-mission-values

1900's

- 1959: Prince Philip, Duke of Edinburgh laid the corner stone
- 1961: Students arrive for the first time
- 1963: IITD was given the right to issue its own degrees

[30]

4.1.2 UNIVERSITY ADMISSION PROCESS

Each university has its own specific admissions process, but there are common trends among these schools. One trend is that universities expect applicants to speak the local language when applying. There are very few options for those who are not fluent in that language. On an admissions page for Todai for example, it specifically states that "most of the undergraduate courses at the University of Tokyo, including those for international students, are conducted in Japanese. Therefore, it is important that all students master Japanese before enrollment."[31] Another commonality that is seen is that universities will accept students from other countries as long as the applicant can provide equivalent education documentation to that of the local education system. The TUM admissions website provides information that says that a German student that is interested in studying at TUM must have a secondary school leaving certificate, letters of motivation and recommendation. While foreign student applicants must apply using the same process as German students, the only difference is that they must provide the equivalent documents to the leaving certificate. [32]

The TUM and IITD admissions pages were less informative than that of MIT or UCL but they provided important information nonetheless. Both universities are looking for great students, but what stood out to the group was that they both require entrance exams when applying for engineering programs. "Using a two-tiered procedure TUM tries to determine whether the applicant is interested in the specific program and whether the applicant is suitable

[30] http://www.iitd.ac.in/content/history-institute
[31] http://www.u-tokyo.ac.jp/en/admissions-and-programs/undergraduate-students/admissions-process/sp-screening-test.html
[32] http://portal.mytum.de/studium/bewerbung/hzb_auslaendisch_en/document_view

for it."[33] With IITD, a noteworthy fact about the examination process is that female applicants do not need to pay for any of their entrance exams, which makes it more attractive for female applicants.[34]

As previously stated, the MIT and UCL webpages have more detailed information given about their respective admissions processes compared to the other universities. Once an applicant has submitted their application to MIT, it is read by a senior admissions officer who looks at the applicant as a whole. If the applicant is strong, then they are moved on to be evaluated by more admissions officers before going on to the selection committee. MIT reports on their admissions webpage that "at least a dozen people will significantly discuss and debate an application before it is placed in the admit pile." [35] MITs selection process is meant to be very precise so that the correct decision is made and that no bias is given to a particular applicant. The process is 'student-centered', so it looks at the individual applicant, not how the applicant is stacked against those applying from the same region, state or school.[36] The freshman class of 2015 had 17,909 applicants, with only 1,742 being admitted, which equates to a very competitive 9.7% admittance rate. In the U.S. a tool to measure a student's educational background and aptitude is the SAT. MIT looks at these scores and takes the crème de la crème. MIT gets a lot of applicants who do well on the SAT but they only admit students who do exceptionally well. For the mathematics section the admittance rate is 14% for student applicants that score between a 750-800; 9% for those scoring 700-740, and 4% for those scoring 650-690[37].

UCLs admissions process is similar to that of MITs and any university in that they are looking for the best students to admit to their school. "We are looking for individuals who are enthusiastic and passionate about learning, who wish to take advantage of every opportunity that UCL will over them and who will benefit from- and contribute to- life at UCL."[38] The University's principal concern "when considering an application is to choose excellent students who are likely to complete their degree program successfully and derive benefit from it."[39] Once

[33] http://portal.mytum.de/studium/bewerbung/eignungsfeststellung
[34] http://jeeadv.iitd.ac.in/
[35] http://mitadmissions.org/apply/process/selection
[36] http://mitadmissions.org/apply/process/selection
[37] http://mitadmissions.org/apply/process/stats
[38] http://www.ucl.ac.uk/prospective-students/undergraduate-study/application-and-entry/ug-selection
[39] http://www.ucl.ac.uk/prospective-students/undergraduate-study/application-and-entry/ug-selection

an applicant submits their application, it is checked over to make sure that they meet the requirements for the university and for the area of study they have applied for. Then the application is reviewed and the applicant's letters of recommendation are looked at, as well as their past grades and predicted academic performance. The admissions selectors are trying to assess qualities such as their academic potential, their motivation for studying a chosen degree, as well as core skills that are required for the program. When UCL is really interested in an applicant they invite them to visit the campus for an ‘open day/selection event’. This invitation serves two purposes. The first is to have the prospective student look at and tour the campus. The second is to speak with members of the staff and present portfolios to aid in the selection process. Since UCL is located in England, its admissions requirements are specific to the United Kingdom’s education system. For admission to UCL a student from the United Kingdom must submit A level and AS level qualifications, International Baccalaureate scores, and even extended project information.[40] These qualifications are similar to those of the Advanced Placement grading in the US. For US student applying to UCL they must have the following: 1. completed four, year-long Advanced Placement courses and attain a 4 or better; 2. Score a minimum of 1800 on the SAT with two subjects of 600 or more each, or; 3. A year of school at a recognized US University and a minimum of 1300/1600 or 1950/2400 on the SAT I.

It is clear that with lengthy application processes that include entrance examinations, very specific prerequisites, and a thorough review of each applicant, each university is invested in accepting only students that will thrive and succeed at their institutions.

WPI on the other hand has a seemingly simple application process. For American students applying to WPI, the process is pretty straight forward. There are two paths an applicant can follow. The first is a Common Application that requires high school transcripts, math or science teacher recommendations, an essay, and SAT or other standardized test scores. The second path is the Flex Plan, where SATs and other scores are not submitted, but projects, research papers, and portfolios are accepted in place of the scores to see the applicant’s problem-solving ability, and project skills.[41] With either option student applicants need to have four years of math including pre-calculus, four years of English, and two years of lab science. International

[40] http://www.ucl.ac.uk/prospective-students/undergraduate-study/application-and-entry/ug-requirements
[41] http://www.wpi.edu/admissions/undergraduate/apply/requirements.html

Students that apply to WPI need to produce the above information or equivalent and show proof of English language proficiency.[42]

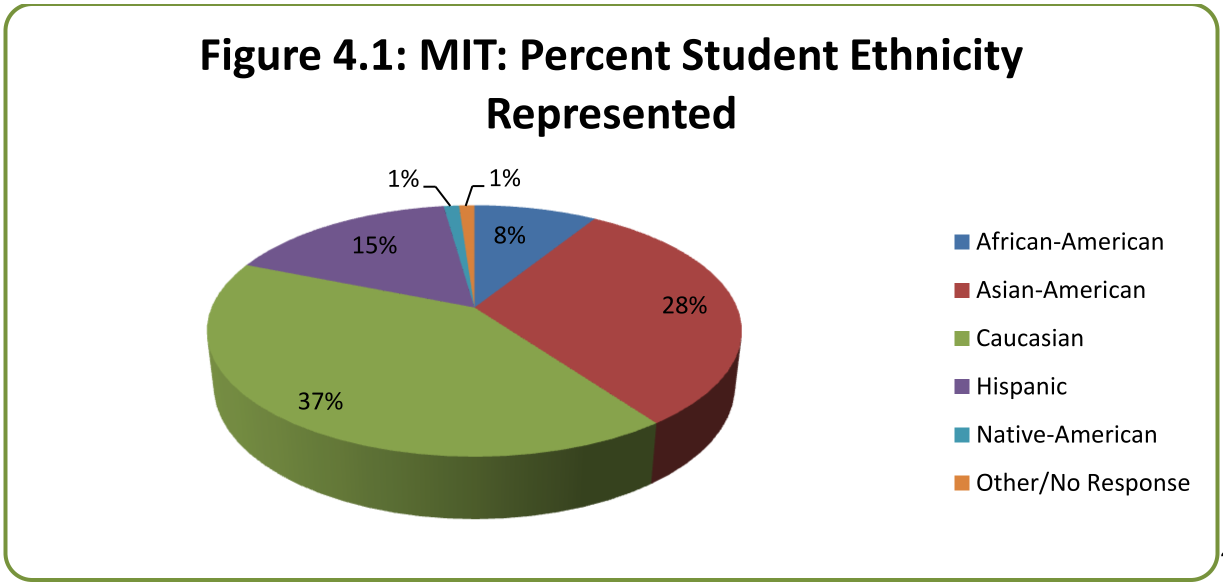
4.1.2.1 STUDENT DEMOGRAPHICS

A diverse student body is important to each of the schools considered in this project. True to their motto, 'Talents in Diversity', "TUM creates a study and work environment in which individual abilities can develop and flourish. The result is a study and work place characterized by vibrant teams, fruitful debate and outstanding research."[43] Some schools historically have had diversity built in to their student community. "UCL was established in 1826 to open up education in England for the first time to students of any race, class or religion."[44]

On each of the university's websites were the varying demographics just mentioned. Some demographics that were looked at in our research were student ethnicity, the location from which the student attended the school, and male to female ratios. Below is further discussion of these demographics and their graphical representation.

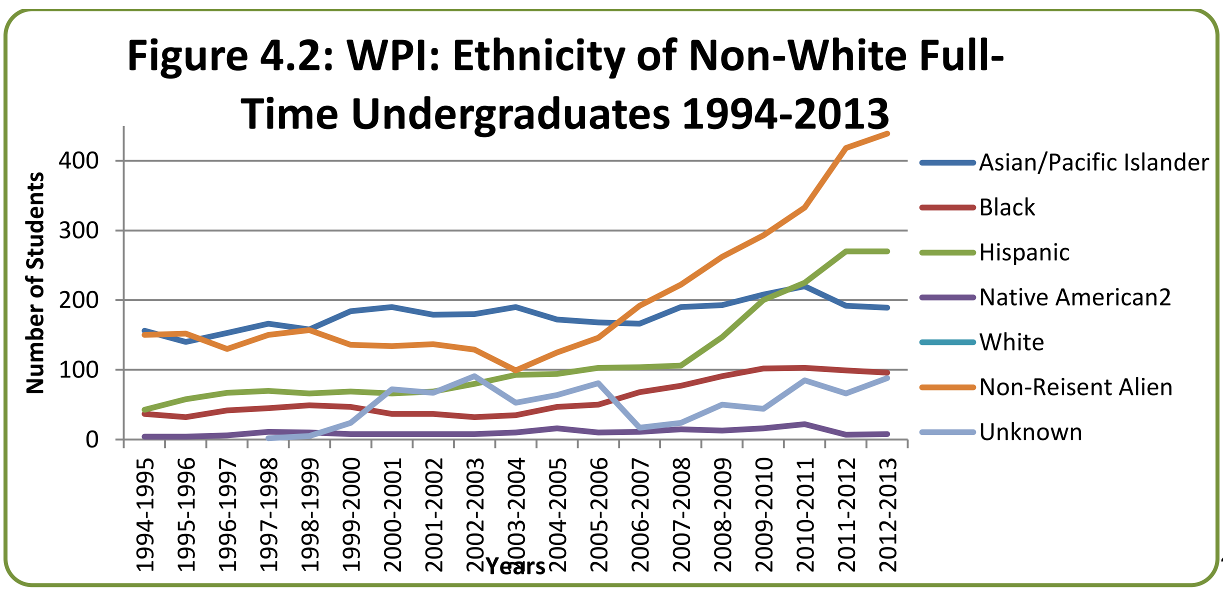
With MITs selection process based on the individual student, there is a wide diversity of students that make up the student body. 90% of students that MIT admitted to the class of 2016 came from 46 of the 50 states in the U.S.[45] Of the 90% of students that come from the United States, 28% identify as being Asian-American while 37% identify as being Caucasian. The figure below shows the ethnic breakdown of the students admitted from the U.S. to the class of 2016.

[42] http://www.wpi.edu/admissions/undergraduate/apply/intl-admissions.html
[43] http://www.diversity.tum.de/en/startseite/
[44] http://www.ucl.ac.uk/about-ucl/
`[45] http://mitadmissions.org/apply/process/profile



[46]

While MIT has a very diverse student population, with only 37% of their students identify as being Caucasian, WPI cannot say the same. Currently, only 32% of its students identify as being in a minority group.[47] The graph below shows the ethnicity of non-white full-time undergraduates from 1994 to the present.



[48]

46 http://mitadmissions.org/apply/process/profile
47 http://www.wpi.edu/Images/CMS/IRO/2012_Fact_Book(10).pdf
48 http://www.wpi.edu/offices/ir/enrollment-data.html

WPI may not have not have the same ethnic diversity that MIT has, but it is clear from the graph above that minority enrollment has been on the rise for more than the last ten years. Now moving from ethnic background toward international backgrounds, we first look at MIT.

Looking again at the class of 2016 on a global scale, MIT admitted 10% of its applicants, who represent 54 different countries. The figure below shows the percentage of international students by the region that they are from.

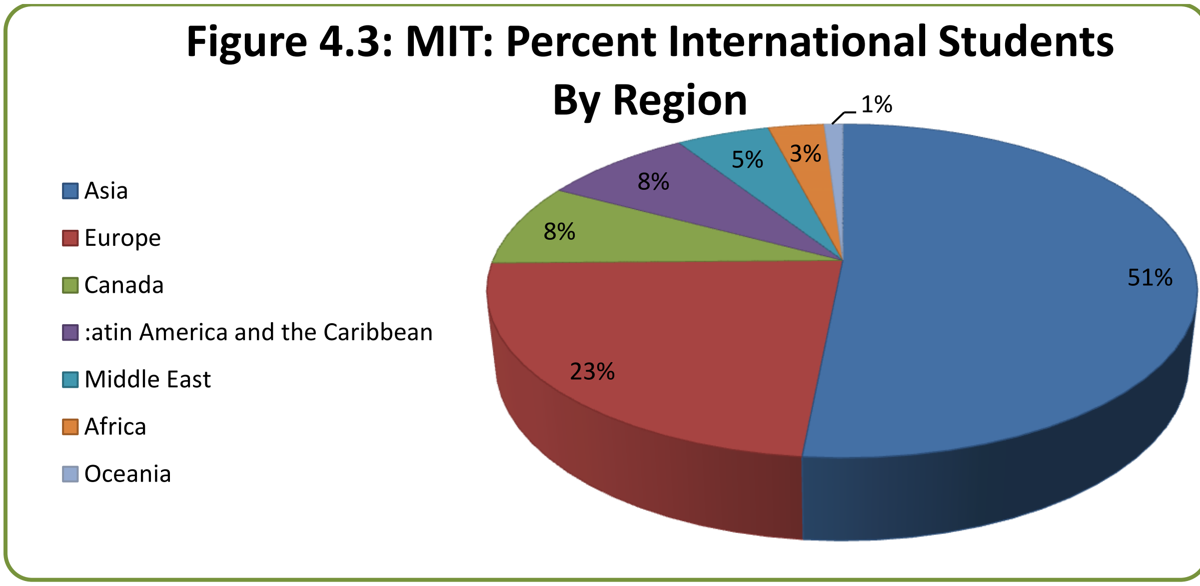
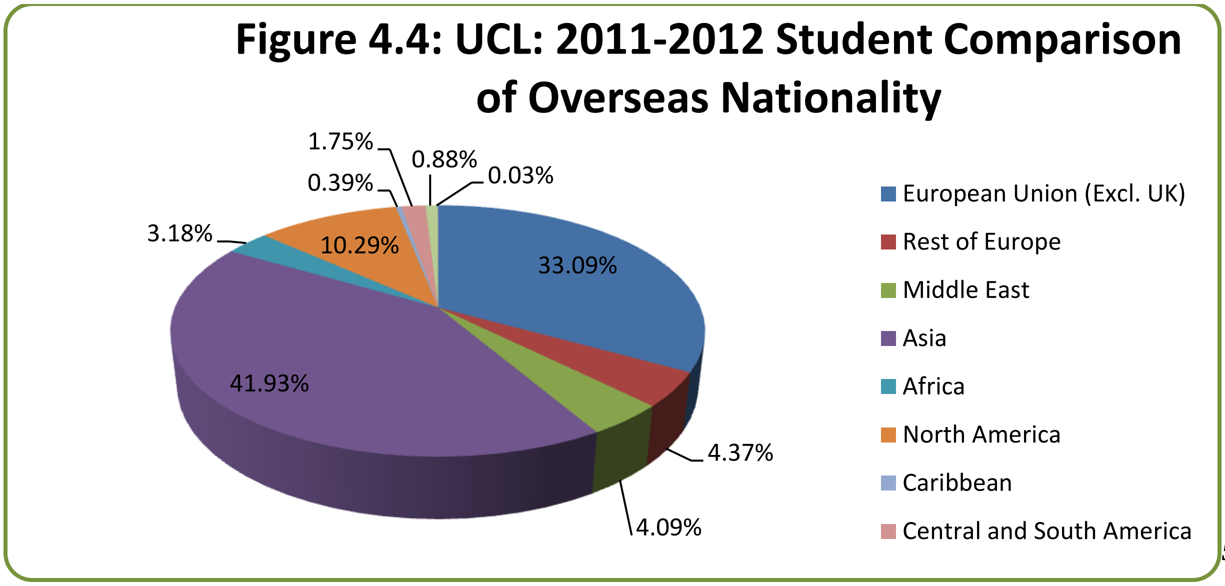


Figure 4.3: MIT: Percent International Students By Region [49]

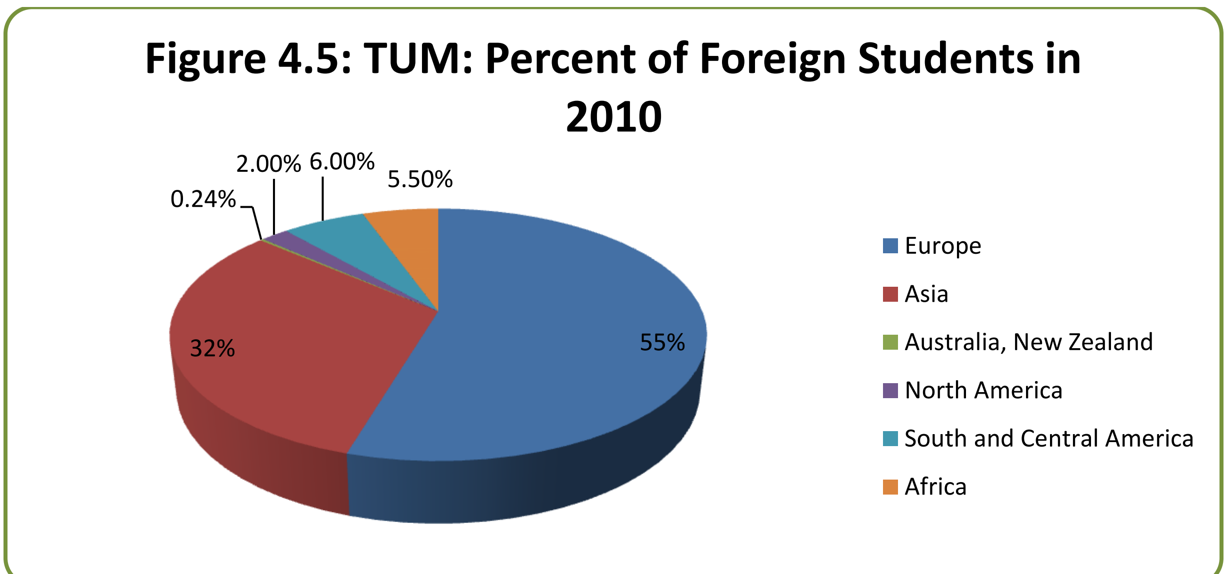
Similar to MIT, UCL has a large majority of its foreign student body coming from Asia and Europe. The following figure shows this majority along with the other percentages of foreign students by region.

[49] http://mitadmissions.org/apply/process/profile



50

At another European school, TUM, there were about 5,000 foreign students making up nearly 16% of the student body in the same year. The figure below shows a breakdown of which regions international students have come from. It shows that most international students are coming from other European nations.[51]



52

[50] http://www.ucl.ac.uk/ras/statistics/current/P
[51] http://portal.mytum.de/cop/statistik/studium/
[52] http://portal.mytum.de/cop/tum_in_zahlen/index_html/

Like TUM, Todai has low enrollment in students from North America. However, this makes sense for Todai because only 9% of the student body is made up of foreign students.[53] Of that 9%, only 15% of students actually come from countries outside of Asia. The following figure shows the actual breakdown of foreign students enrolled in undergraduate programs.

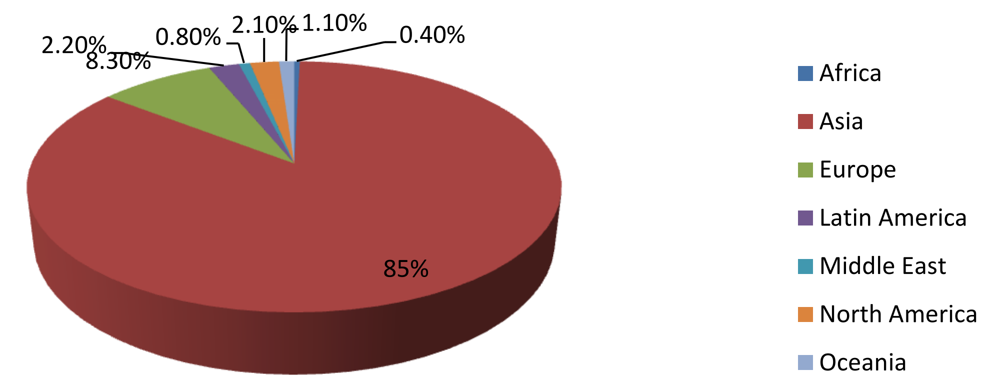


Figure 4.6: Todai: Students Enrolled in Undergraduate Studies in 2011 by Region

54

A significant amount of information has just been presented on ethnic and international backgrounds of students at some of these top universities, but one question that hasn't been addressed is: What does the difference in gender look like? Looking at MIT, UCL, Todai, TUM and WPI respectively, a good picture of male and female enrollment is presented.

Total female enrollment at MIT has been on the rise for the last a decade. The figure below shows the total number of both male and female undergraduate between 1998 and the present day. From the graph, you can see that, for the first half of the last decade, male enrollment was decreasing while female enrollment started to climb. The ratio between males and females has slowly narrowed and today the class of 2016 has a reported 54% to 46% male to female ratio.[55]

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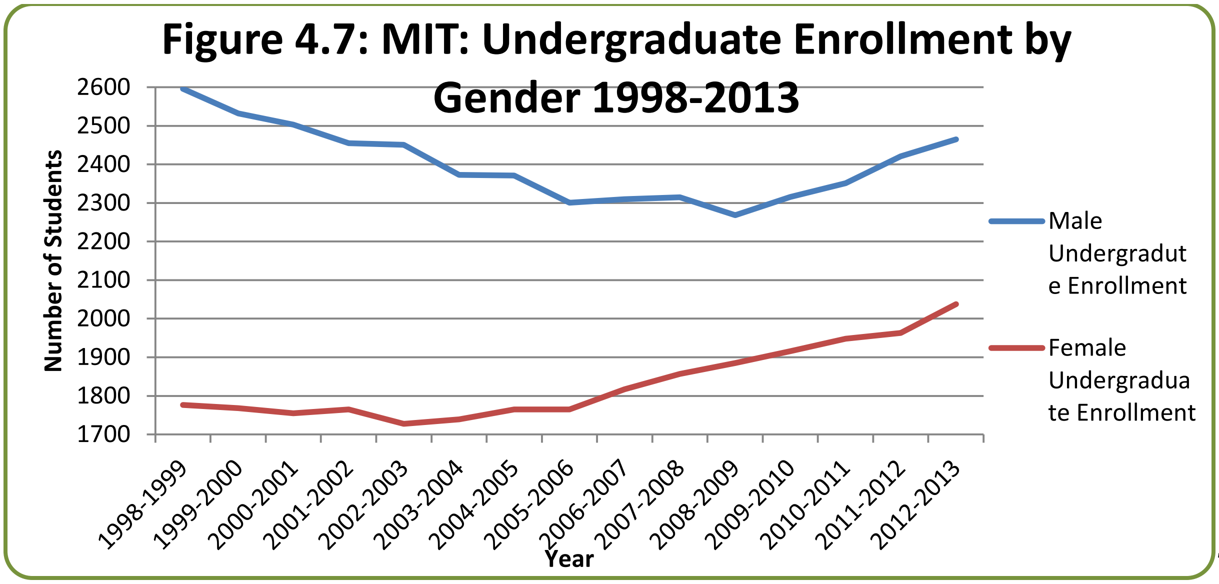
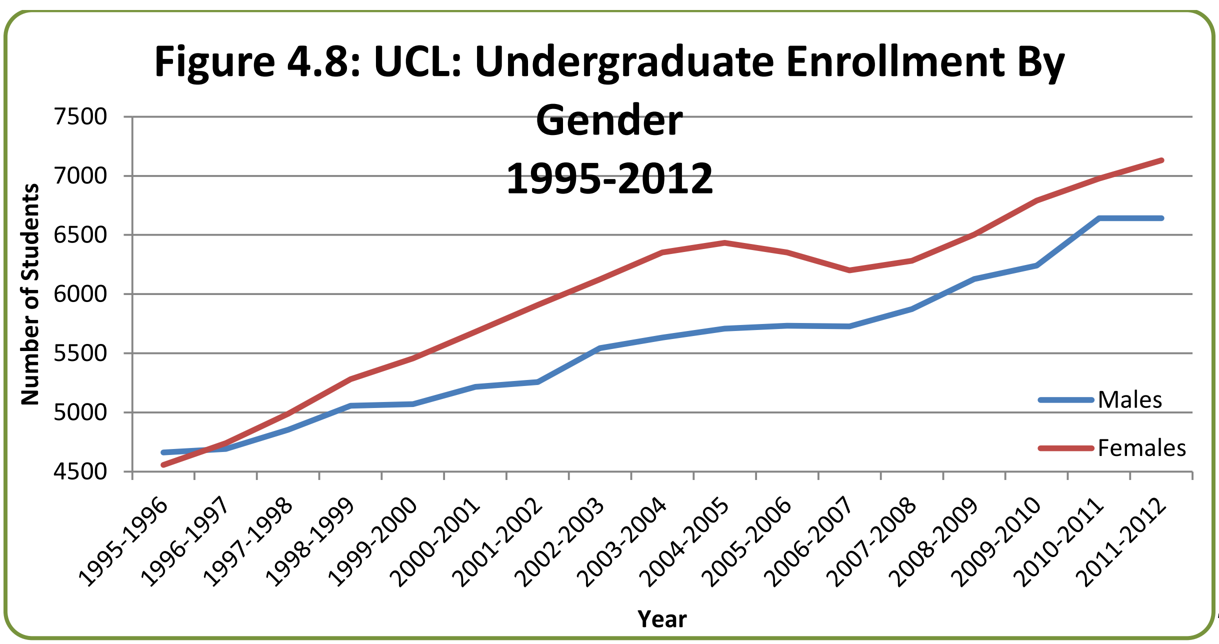
[53] http://www.u-tokyo.ac.jp/en/about/data/enrollment.html
[54] http://www.u-tokyo.ac.jp/en/about/data/international-students.html
[55] http://mitadmissions.org/apply/process/profile



[56]

Although total enrollment at MIT has gone up, it is clear to see that the gender gap has been narrowed. The same cannot be said about UCL. The figure below shows the school (UCL) as a whole has grown in size between 1995 and the present. It also shows that the margin of difference between male and female enrollment has stayed fairly even over that time period.



[57]

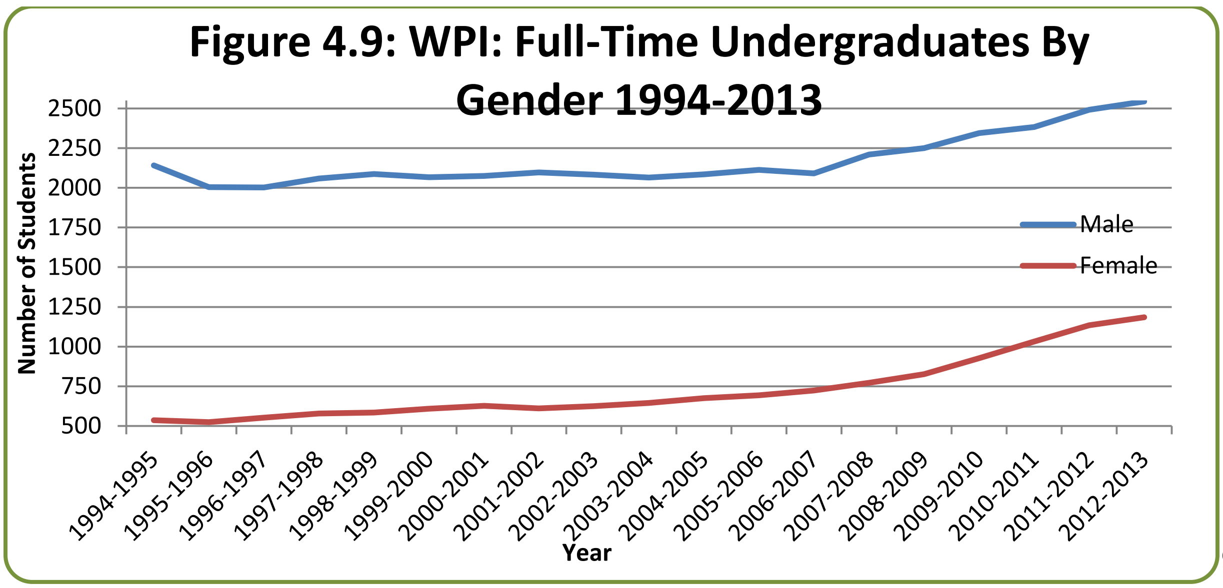
UCL is different from the other schools that were researched because it has a higher female percentage in the student body. This is likely because of many factors, one of which is the

[56] http://web.mit.edu/registrar/stats/gender/index.html
[57] http://www.ucl.ac.uk/ras/statistics/archive/year_index/F

different majors offered by UCL, but the most likely one is that, "UCL was the first university to welcome female students on equal terms with men"[58], so there has been more time to overcome the gender gap seen at most other schools.

Todai has a large difference between male and female enrolled undergraduates. Females make up roughly 20% of the population while males make up the remaining 80%. Similarly TUM had a large gender gap in 2011. In that year TUM had roughly 31,000 total students and of those, about 10,000 were female students, which make up about one-third of the student population.[59]

WPI, like the other schools mentioned above, has a major gender gap. The graph below shows male and female enrollment from 1994 to the present.



[60]

It is easy to see the gender gap in the above graph, and the trend that in recent year's female enrollment has increased significantly. Currently 31.8% of the student body is female, which is almost a 12% increase in female enrollment from the 1994-1995 academic year, which had a 20% female enrollment.

Female enrollment at these universities may be disproportionally represented, but it is clear that this disproportionality is slowly diminishing. UCL is an example of a university that,

[58] http://www.ucl.ac.uk/about-ucl/
[59] http://portal.mytum.de/cop/statistik/studium/
[60] http://www.wpi.edu/offices/ir/enrollment-data.html

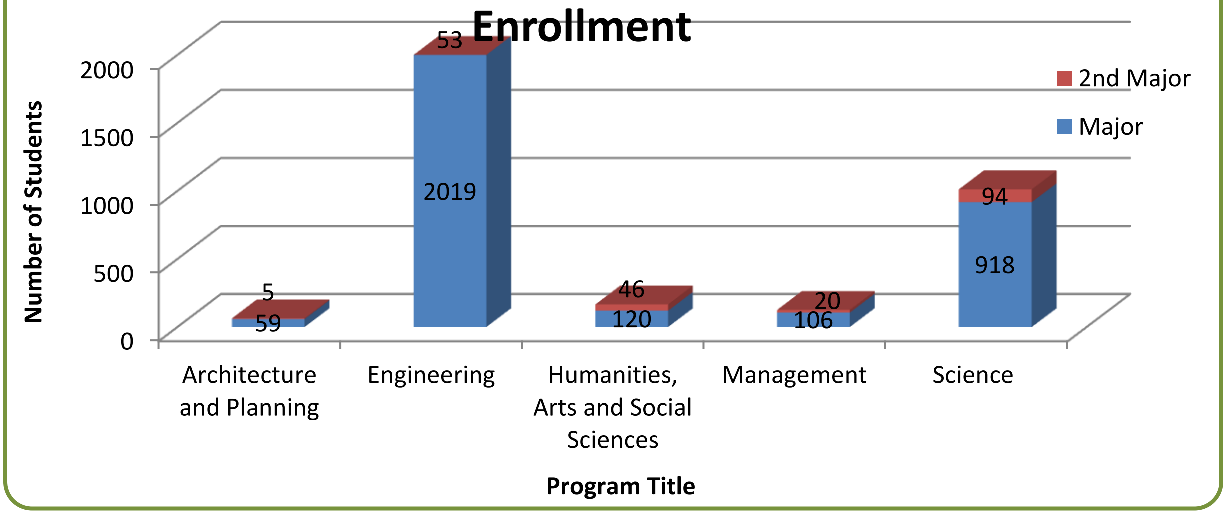
according to enrollment numbers, has seemingly overcome the gender gap. While this does not take into account the variety of majors, the trend still holds.

4.1.3 UNIVERSITY PROGRAMS OF STUDY

In the introduction section of this report, the 'Forbes 15 Most Valuable Majors' table was presented, and later a list of specific majors that the group wanted to look into was also presented. This list included the majors of: Biological Engineering, Civil Engineering, Electrical Engineering, Mechanical Engineering, and Software and Systems Engineering. In this section of the report, data is presented on enrollment in engineering programs at respective universities as well as information on how students enroll in these programs.

Looking first at MITs degree programs and the graph below, there are five schools of study: Engineering, Science, Management, Humanities/Arts and Social Sciences, and Architecture.[61] These five schools encompass over 30 degree programs that MIT offers.[62] It also can be seen from the graph below that an overwhelming majority of students are enrolled in engineering degree programs. In fact, if you sum all other areas of study together, they still do not equal the enrollment of those in engineering.

Figure 4.10: MIT: Undergraduate Program Enrollment



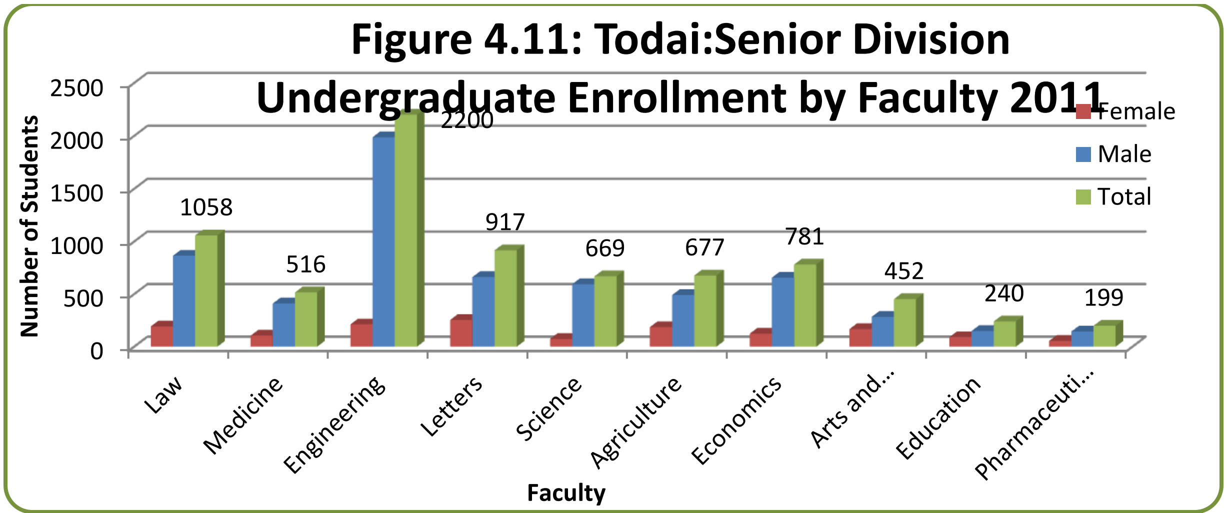
[61] http://mitadmissions.org/discover/academics
[62] http://web.mit.edu/catalog/overv.chap3.html

An interesting concept that came up in the research was that MIT does not allow you to select a major when you first apply to the school, therefore all freshmen year students' majors are considered to be undeclared. “During the freshman year, MIT will provide academic fairs, lectures, seminars, and other programs to help students determine which major will suit those best; they then are free to choose from MIT’s majors, without any additional requirements or admission procedures.”[63]

Similar to MIT, Todai doesn’t allow its students to start off in a specific degree program; instead Todai has its undergraduate students complete basic courses in their first two years of education. There are two levels to undergraduate studies. The first is the ‘Junior Division’ in which students in the first two years are assigned to six paths of study upon entrance to the university. In these years they learn the basics and take classes in Humanities /Social sciences or the natural science and study various liberal arts. The second level is the ‘Senior Division’ for students in their 3rd and 4th year. In these years they go into one of 50 departments in ten faculties based on their preference, aptitude and performance in their first two years of education.[64]

As previously stated, Todai has ten faculties with many departments within those faculties. The most populous faculty is engineering, which has 16 different departments and degree programs. The figure below shows the enrollment of 3rd and 4th year students in the different faculties in 2011.

[63] http://mitadmissions.org/discover/majors
[64] http://www.u-tokyo.ac.jp/en/admissions-and-programs/undergraduate-students/index.html#a001

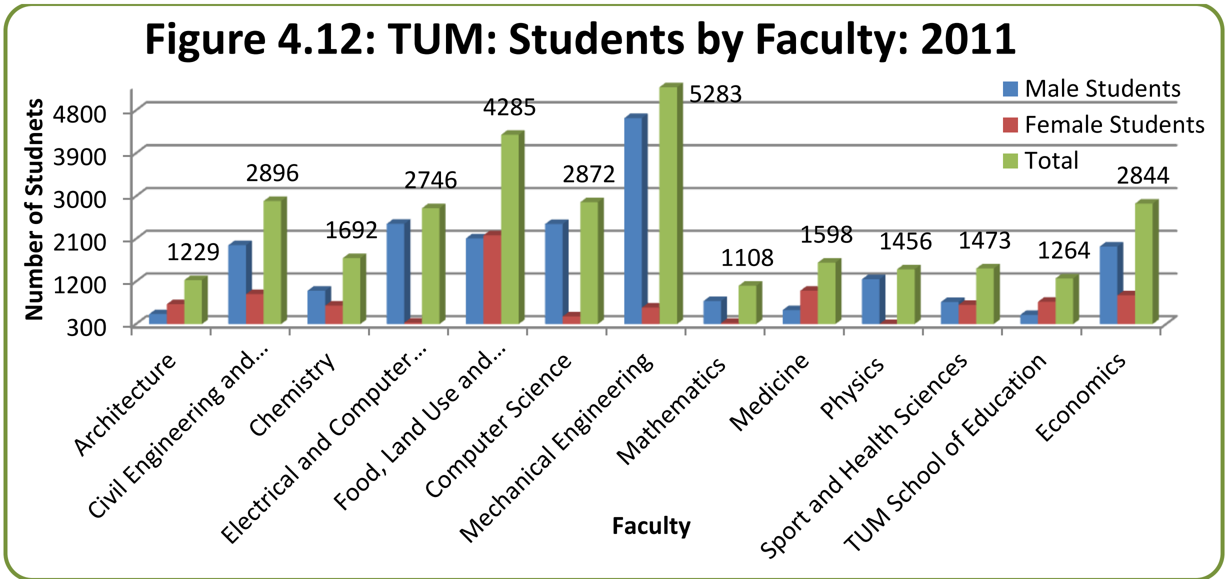


[65]

It is clear to see that engineering has the most students enrolled with the second most popular major, law, having roughly half as many students enrolled. Also in this graph, the total enrollments for each department are broken down by gender. When looking specifically at gender, engineering is the most populous for males and a very close second for females compared to other departments.

Two other universities that were looked at which also gave enrollment in degree program areas by the total number of students and by gender were TUM and IITD. TUM has 13 academic departments or faculties and offers 50 different bachelor's degree programs.[66] Enrollment in these programs is skewed in respects of the number of male and female students enrolled and are shown in the graph below.

[65] http://www.u-tokyo.ac.jp/en/about/data/enrollment.html
[66] http://portal.mytum.de/cop/statistik/studium/

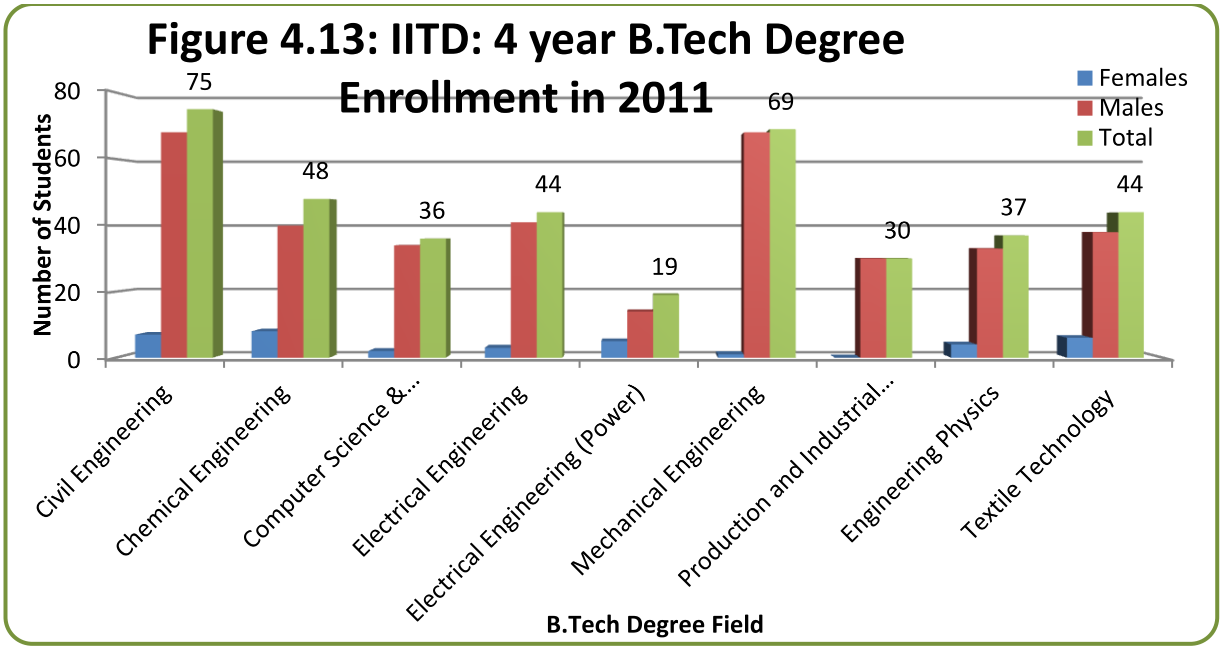


67

In the graph it shows that Mechanical Engineering is the most populous degree faculty, but has an overwhelming majority of male students at roughly 87%, compared to female students at nearly 12%. This trend of a high male enrollment is common in other faculties also.

IITD on the other hand offers many courses in undergraduate and postgraduate studies; but there are three paths of study that students can apply for. The first is a four year degree earning a Bachelor's of Technology (B.Tech) in one of nine basic degree program areas. The second is what is considered at Dual Degree Program in which over five years a B.Tech and a Masters of Technology (M.Tech) is earned in one of five different disciplines. The third is an Integrated Degree Program, in which students earn an M.Tech in Mathematics and computing over five years of study.[68] The figure below shows the enrollment in the first degree path of a 4 year B. Tech. It shows not only a total enrollment but also a breakdown in the male and female enrollment.[69]

[67] http://portal.mytum.de/cop/statistik/studium/
[68] http://www.focusdelhi.com/education/iit-delhi.html
[69] http://www.way2k.com/iit-delhi-iitd-2011-placement-salary-statistics.aspx

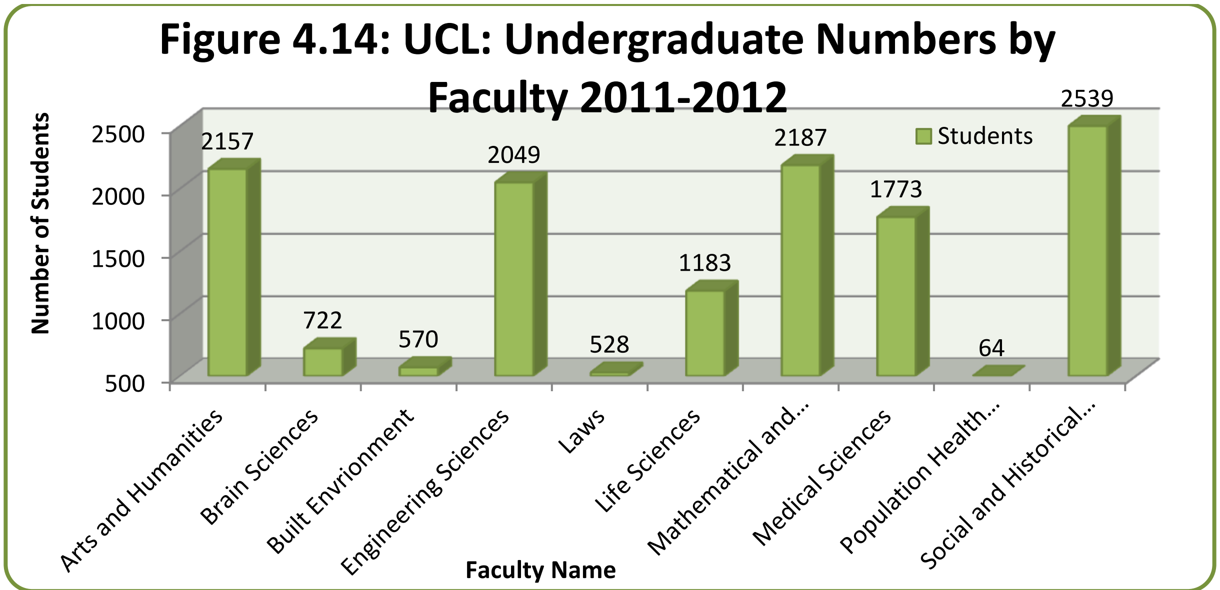


[70]

From this graph, much like the TUM graph, the disproportionate enrollment of male students compared to female students is noticeable. At IITD, unlike TUM however, civil engineering is the leading major with mechanical coming in at a close second.

Of the top universities that were looked at, only one had engineering missing as its top area of study; that university was UCL. Studies at UCL are separated into Faculties, which are then divided into Subjects, which in turn are separated into degree Programs. UCL has 11 faculties that cover a range of areas to study in. An example of how the separations and divisions work would be that in the Engineering Science Faculty there are eight Subjects. One Subject taking this example even further is Civil and Environmental Engineering which has six degree programs.[71]

[70] http://www.way2k.com/iit-delhi-iitd-2011-placement-salary-statistics.aspx
[71] http://www.ucl.ac.uk/prospective-students/undergraduate-study/degrees-1314/search/faculties



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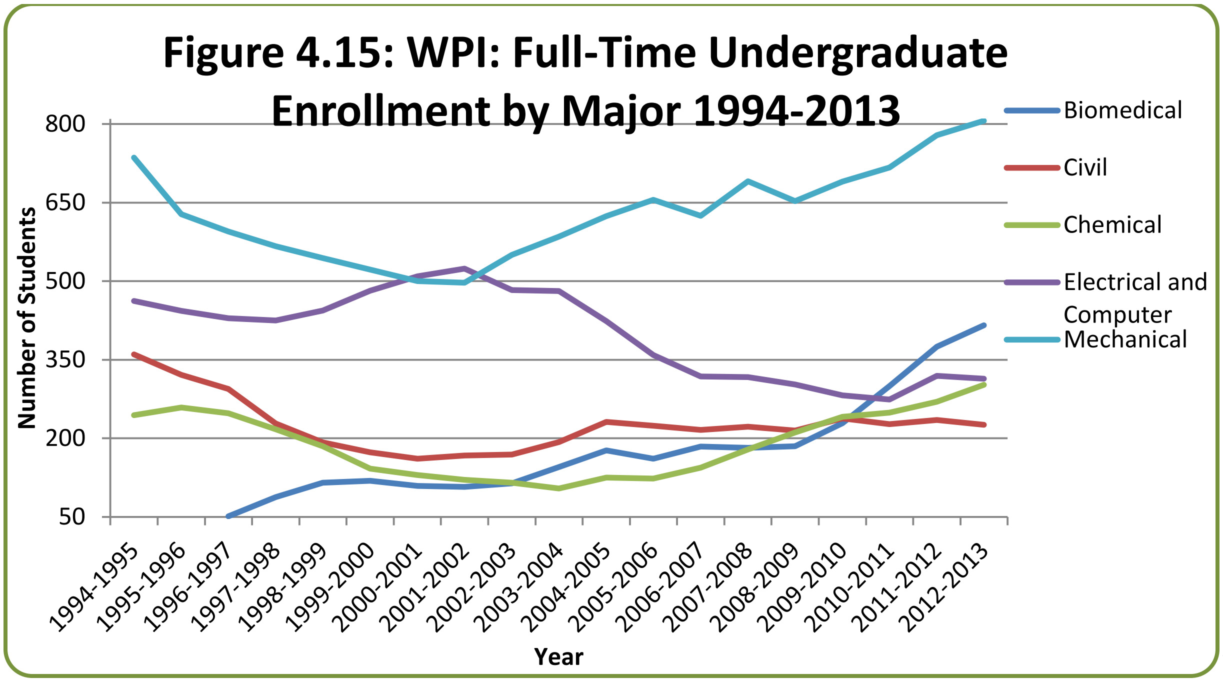
The figure above shows the number of undergraduates enrolled in ten of the eleven Faculties in the 2011-2012 academic year. The graph also shows that engineering is the fourth most populated program at UCL.

Among the universities mentioned a clear trend is evident. With the exception of UCL, engineering degree programs attract the most students. Of those enrolled in engineering, the focus tends to be in the five majors that were selected for this project, with mechanical engineering being the most dominant. Looking at WPI and the enrollment in the five majors of interest over the last 20 years we can see in the graph below that mechanical engineering has been the most popular.

[72] http://www.ucl.ac.uk/ras/statistics/current/B



73

The most interesting take away from this graph is the trends in enrollment in the last six academic years. It shows that enrollment in each of these areas had an increase in enrollment. In the late 1990s a decline in enrollment is evident but then, in recent years, enrollment has been on the rise. This could be due to higher interest in these areas or, to note, just the natural cyclical pattern of enrollment in the different majors.

4.1.4 SCHOLARLY INSIGHT

The data from the universities presented in the previous section is great for making some conclusions about engineering education, but there have been several great papers on this topic which would contribute valuable information to the discussion.

The first two publications looked at were “Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future” and “Rising Above the Gathering Storm Revisited: Rapidly Approaching Category 5”, both of which were produced by the National Academy of Science, National Academy of Engineering, and Institute of Medicine. The first of these two publications presents the poor state of the United States education system, specifically in math and science. The publication presents various points of failure. One in

[73] http://www.wpi.edu/offices/ir/enrollment-data.html

particular is that there are many unqualified teachers teaching a subject in which they have never majored in. The points of failure are followed by suggestions for fixing these problems. The New York Times published an article discussing this publication, citing one of the problems outlined and the solution presented. “It decries the dismal state of math and science education and calls for an ambitious national program that would retrain the current teacher core, while attracting 10,000 new math and science teachers into the profession every year for the foreseeable future.”[74] The second publication is a follow up to the first one, looking back over a five year period between the two publications. The follow up publication basically outlines that the efforts taken out of the first publication have failed to improve the outlook of the country. The biggest position of this follow up is that other nations have quickly advanced in recent years and that the US has not seen the same advancement.

A third publication that was looked at was written by James J. Duderstadt, a former President of the University of Michigan, entitled “A University for the Twenty-first Century”. As the title suggests, this publication is based on what the university of the future should look like. Duderstadt claims that, among other things, the quality of today’s education isn’t what it used to be, that the curriculum of schools is no longer the most important aspect of education, and that today’s students will be lifetime learners. In fact, Duderstadt says, “Today’s college graduates will face a future in which perpetual education will become a lifetime necessity since they are likely to change jobs, even careers, many times during their lives. To prepare for such a future, students need to acquire the ability and the desire to continue to learn, to become comfortable with change and diversity, and to appreciate both the values and wisdom of the past while creating and adapting to the new ideas and forms of the future.”[75] Another concept presented is that of diversity in academia. He says that; “When one discusses the topic of diversity in higher education, it is customary to focus on issues of race and ethnicity, and we shall do so in much of this chapter. But it is also important to recognize that human diversity is far broader, encompassing characteristics such as gender, class, national origin, and sexual orientation. These, too, contribute to the nature of an academic community.”[76] He goes on to

[74] http://www.nytimes.com/2006/01/24/opinion/24tue2.html
[75] “A University for the Twenty-first Century” Ch. 4
[76] “A University for the Twenty-first Century” Ch. 9

state that students learn from each other and that having a more diverse student body will increase exposure to varying ideas, which will produce better students.

The final two publications looked at were "The Engineer of 2020: Visions of Engineering in the New Century" and "Educating the Engineer of 2020", produced by the National Academy of Engineering. Addressing the first of these two publications, it identifies the ideal attributes needed in the engineer of 2020, as well as ways to improve the training of these engineers. Two statements regarding the attributes of these engineers stood out. The first of these was, "In the past those engineers who mastered the principles of business and management were rewarded with leadership roles."[77] The other states, "Given the uncertain and changing character of the world in which 2020 engineers will work, engineers will need something that cannot be described in a single word. It involves dynamism, agility, resilience, and flexibility."[78] The second publication discusses ways to improve education of these engineers. It is similar to the first two publications discussed because it calls for a change to education in grades K-12. It discusses a specific program to enrich middle school and high school education called Project Lead the Way (PLTW). PLTW is a "curricula of hands-on, problem-based, technology-driven learning"[79]. This type of education and set of skills is what the first publication outlines engineers for the future needing.

These publications from several prestigious institutions paint a picture of what is wrong with education, what needs to be done to better educate our youth and engineers, and also what the future needs of these students so that education can be better geared towards those needs.

4.1.5 CONCLUSIONS

In terms of education, this project sought to examine the global trends in engineering majors, look at the techniques used to educate engineers in the US and globally, and to determine trends in demographics regarding the diversity of American engineers. With the information presented, a number of conclusions can be drawn regarding these goals.

[77] "The Engineer of 2020: Visions of Engineering in the New Century" Ch. 4
[78] "The Engineer of 2020: Visions of Engineering in the New Century" Ch. 4
[79] "The Engineer of 2020: Visions of Engineering in the New Century" Ch. 4

A number of notable trends appeared throughout the research, including a strict admissions process for highly ranked universities, the guidance that these universities provided for their students, an increased enrollment in engineering majors, and a striking lack of diversity in STEM majors. James Duderstadt, in his publication "A University for the 21st Century", outlines several "steps in the transformation process" that a university should undergo to be all it can be. These are: "Step 1: Commitment at the Top; Step 2: Seeking Community Involvement; Step 3: Igniting the Sparks of Transformation; Step 4: Controlling and Focusing the Transformation Agenda; and Step 5: Staying the Course." But before our universities can undergo this process of transformation, they must identify what needs to be changed.

Having stricter admissions requirements, such as those employed by MIT, will allow universities to accept those students which have the most potential for success. However, this selectivity comes at a higher cost, both in the amount of money and the number of students. Currently, the metrics used to compare students and measure their academic aptitude include tests such as the SAT and ACT. These metrics have proven to be useful in identifying the top students, but not every country uses this method to measure their students. UCL and the whole of Great Britain, for that matter, use A level and AS level qualifications, International Baccalaureate scores, and even extended project information when selecting their students. It isn't uncommon for a student to submit projects or other pieces of work to prove their ability when applying to a university. A stricter enrollment process, perhaps utilizing a new metric, would lead to stronger students being selected for universities. With stronger students, there will be a larger pool of highly trained, competent engineers available to work in the industry and teach a new generation of engineers and scientists. Project Lead The Way (PLTW), mentioned in the "Educating the Engineer of 2020" publication by the National Academy of Engineering, and other similar programs, could potentially provide a new metrics for schools to measure their applicants by. With schools selecting those "students [who] see the real value of math and science and its varied applications to high-tech engineering" , universities will have students who are ready to meet the challenges and rigors of college. A member of this group was a student in a high school whose curriculum was based solely on PLTW courses; he has stated that he feels like it better prepared him for college and, more specifically, the engineering software that he has used in his major. Changing admissions processes to have a more thorough set of metrics will cost money, manpower, and potentially lead to fewer students at first, but top universities outlined in this project have shown that, even with a selective admissions process, students were still eager to join the ranks of those who are already enrolled.

The globally ranked universities looked at had the most students in their entire student bodies enrolled in engineering and STEM-related programs. More specifically, areas such as Biomedical Engineering, Civil Engineering, Electrical Engineering, Mechanical Engineering, and Software Systems Engineering saw the greatest enrollment. Since there is a demand for qualified engineers in these fields, it is important that enrollment in these fields continues to grow. Programs that reach out to younger students, such as the aforementioned Project Lead The Way, could generate interest in STEM-related fields at the K-12 level, helping to bolster enrollment in engineering fields. Furthermore, these projects should aim to reach out towards women and minorities to attract these underrepresented groups towards STEM majors.

A final point worth discussing is the need of a more diverse student body. In "A University for the 21st Century", James J. Duderstadt discusses diversity as a broader topic than just race and ethnicity; it also "[encompasses] characteristics such as gender, class, national origin, and sexual orientation." The data collected shows that universities are closing the gender gap in engineering programs in addition to having an increased number of students from foreign countries. Universities that try to create a culturally mixed student environment understand that it will ultimately lead to having better, well-rounded students who will learn about and from each other. James Duderstadt further states that "Students constantly learn from each other in the classroom and in extracurricular life. The more diverse the student cohort, the more opportunities for exposure to different ideas, perspectives and experiences and the more chances to interact, develop interpersonal skills, and form bonds that transcend difference." The National Academy of Engineering in its report "The Engineer of 2020" states "The world in which technology will be deployed will be intensely globally interconnected. The population of individuals who are involved with or affected by technology (e.g., designers, manufacturers, distributors, users) will be increasingly diverse and multidisciplinary. Social, cultural, political, and economic forces will continue to shape and affect the success of technological innovation. The presence of technology in our everyday lives will be seamless, transparent, and more significant than ever." Engineers of the future will need to be able to think 'out of the box' and come up with creative solutions to problems. If a university has only educated engineers of the same demographic or background, then new ideas may not be generated as easily. James Duderstadt says "Intellectual Vitality Diversity is similarly fundamental for the vigor and breadth of scholarship. Unless we draw upon a greater diversity of people as scholars and students, we cannot hope to generate the intellectual vitality we need to respond to a world characterized by profound change."

The need for a more rigorous enrollment process, more guidance in major selection, increased enrollment in engineering programs, and a more diverse student body are evident. A more rigorous enrollment process would include using different metrics that more accurately measure a student's ability based on previous experiences. By using this, combined with the traditional report card and test scores, schools can better predict which students will be a better match for their school and enjoy continued success. Once accepted, the schools should provide guidance to help students find the major that is the right fit for them. Guidance for students will help them feel comfortable in their major, therefore decreasing the drop-out rate and increasing the number of students completing engineering programs. By having a more diverse student population, students will be introduced to ideas from outside of their cultural norms. This will allow them to approach engineering problems with a more global perspective.

4.2 JOBS

In this section discussing jobs, research into the different areas that influence the creation of jobs in the United States will be shown, as well as the effect innovation has on the overall economy and how to generate more innovation. The example of a regional cluster in New York State is given as the proof of how partnerships of universities, industries, and governments can have a positive impact on both the local region where it is centered and the nation as a whole.

4.2.1 INNOVATION

How are jobs created? Jobs can be created through innovation. Quite simply, businesses make things that people want to buy and then they improve them. From the steam engine to the space shuttle or from the earliest main frame computer to the iPhone, America's record of innovation and economic growth is unsurpassed. Apple Inc. is known worldwide as one of the most innovative companies in the world. What has Apple done for job creation? "Throughout our history, Apple has created entirely new products – and entirely new industries – by focusing on innovation. As a result, we've created or supported nearly 600,000 jobs for U.S. workers:

from the engineer who helped invent the iPad to the delivery person who brings it to your door."[80]

The Information Technology & Innovation Foundation defines innovation as "….the improvement of existing or the creation of entirely new products, processes, services, and business or organizational models—drives long-run economic growth and quality-of-life improvements."[81] America's investment in education, science, research and development, and infrastructure gave the tools needed to innovate and grow the economy. The Commerce Department estimates that up to 75 percent of economic growth since World War II is the result of technological innovation.[82]

Advances in technology can be a double edged sword. There will always be winners and losers. Some of the greatest innovations of their time no longer exist. Polaroid cameras and Kodak film are virtually gone, replaced by newer, better, and cheaper digital technology. As technology advances, it both creates and destroys jobs and industries. Higher-skilled and more productive jobs that receive higher pay eliminate the outdated lower-productivity jobs. "Historically, the income generating effects of new technologies have proven more powerful than the labor-displacing effects: technological progress has been accompanied not only by higher output and productivity, but also by higher overall employment."[83]

The creation of wealth is one of the greatest motivating factors for entrepreneurs and investors. As businesses change, modify, reinvent, or reposition a product or service it adds value. When value is added, people will buy more of the products. If the United States had to compete on price alone, its economy would be much worse off than it is today. "Innovation is the only thing that can save our country."[84] Products that are made elsewhere in the world can be produced far cheaper and on a greater scale than in America. In order to compete with that,

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[80] http://www.apple.com/about/job-creation/

[81] The Good, The Bad, and The Ugly (and The Self-Destructive) of Innovation Policy: A Policymaker's Guide to Crafting Effective Innovation Policy, The Information Technology & Innovation Foundation, October 2010, Page 13.

[82] Ideas in Action with Jim Glassman, "Is America Suffering an Innovation Gap?" July 9, 2010, http://www.itif.org/media/america-suffering-innovation-gap.

[83] Organization for Economic Co-operation and Development, "The OECD Jobs Study: Facts, Analysis, Strategy," 1994, http://www.oecd.org/dataoecd/42/51/1941679.pdf.

[84] Attributed to Dean Kamen in the book Creating Innovators, The Making of Young People Who Will Change the World, Tony Wagner, Scribner, 2012, pg. 6.

businesses here in the United States need to be the creators of the intellectual property that generates wealth. "A pill that cures cancer is worth $1 million an ounce. The real value is now in the creation of ideas that are scalable, that don't consume resources, that aren't a zero-sum game."[85] These ideas could be a cure for cancer or a way to generate energy free pollution. As long as these ideas start in America, the wealth they create will be enjoyed here.

4.2.2 INNOVATION CLUSTERS

"Innovation clusters are regional concentrations of large and small companies that develop creative products and services, along with specialized suppliers, service providers, universities, and associated institutions. Ideally, they bring together a critical mass of skills and talent and are characterized by a high level of interaction among these entrepreneurs, researchers, and innovators."[86] The success of clusters in both productivity and innovation has created a demand worldwide for the people and resources needed.

Clusters in the U.S. have typically developed in areas where the private sector, government funded labs and research universities interact on a regular basis such as in the city of Boston. They have also formed in areas where private industry works regularly with research universities and with funding from the government. Silicon Valley is one example. Another method would be the intentional location of related businesses and industries within a geographical location such as Tech Valley, which is centered around Albany, NY.

This shared use co-location model was used by New York State when they began their Nanotechnology initiative. Dating back to 1993, former New York Governor Mario Cuomo provided $10 million to fund a Center for Advanced Technology to conduct cutting edge research on next generation computer chip technologies. Sixteen years later, this regional cluster extended from Albany to Buffalo to New York City, and North Country and Long Island. The Empire State Development Corporation (ESDC) has estimated that as of 2009 this cluster is

[85] Attributed to Dean Kamen in the book Creating Innovators, The Making of Young People Who Will Change the World, Tony Wagner, Scribner, 2012, pg. 6.

[86] National Academies Symposium on "Growing Innovation Clusters for American Prosperity, Page 3, http://www.nap.edu/catalog.php?record_id=12926.

home to over 800 companies, with over 364,000 high-tech jobs. The average annual income is over $75,000 for a total payroll of approximately $26 billion.[87]

Cluster development programs are used in several other nations, including Japan, Korea, China, and some in the European Union. The United States does not have a national program to develop clusters.[88] Once the conditions for innovation are in place, the five elements of job creation can be used to exploit the innovations.

4.2.3 THE FIVE ELEMENTS OF JOB CREATION

Job creation strategies work when they are focused and when they remove all of the obstacles to job creation. A focused effort should be made towards specific industries along the entire value chain. Once the groundwork for innovation has been laid, the next focus is job creation. From a policy perspective, there are five key elements to job creation. The first is to identify labor intensive subsectors that have a global competitive advantage or strong domestic demand. Second is to improve access to capital for those sectors and to incentivize banks to increase lending, allow foreign investment, and educate new borrowers. Third is to build suitable infrastructure to support those sectors and the regions in which they are located. This is where clustering has proven to be so successful. Fourth is to cut unnecessary regulation, bureaucracy, and corruption. The process of building a business needs to be simplified to reduce time and expense. Finally, there must be public and private cooperation and buy-in to provide a suitable workforce with the education and technical skills needed for jobs in those sectors.

The first element of job creation is selecting one or more labor intensive industries to be the country's global competitive advantage and provide for a strong demand at home. More advanced economies would be looking for industry sectors where the creation of high-paying jobs is likely while lesser developed nations may be focusing on just putting people to work. In the United States, the Obama Administration has chosen to focus on 21st century technologies in the hope of creating new high-paying jobs. The United States national priorities for innovation include clean energy, with the intent of creating a secure and independent energy future for America, biotechnology and other health care information technologies, to reduce costs, prevent

[87] Pradeep Haldar, Presentation at June 3, 2009, National Academies Symposium on "Growing Innovation Clusters for American Prosperity", Page 64.
[88] National Academies Symposium on "Growing Innovation Clusters for American Prosperity, Page 3, http://www.nap.edu/catalog.php?record_id=12926.

errors and improve outcomes, nanotechnology, advanced manufacturing, space capabilities with applications for communications, navigation and national security, and educational technologies that may help students learn and train workers for 21st century jobs.

The second element of job creation is to improve access to funding and incentives. A business needs capital to grow, and new businesses are the hardest to fund. The United States strategy for innovation includes Research and Experimentation Tax Credits and development investments. The Startup America initiative provides early-stage seed financing for growing new businesses.

The third element is infrastructure. Infrastructure must be available for businesses to locate in a specific country or region. Energy, water, communications, roads, sewers, airports, and railroads are all requirements for growth. Typically, these elements can only be provided by government either regionally or nationally. In the U.S., infrastructure investment is focused on high-speed rail, the next generation of air traffic control, and a National Infrastructure Bank.

The fourth element is to eliminate unnecessary bureaucracy and regulation. This adds time and expense to the cost of doing business that startup businesses simply can't afford. The Department of Commerce published a paper on patent reforms that addresses "the abundant evidence demonstrating that timely, high-quality patents drive innovation and, conversely, that delay, uncertainty, poor quality, and inefficiencies in existing legal processes impede innovation."[89]

Finally, the fifth element requires a strong public-private partnership to educate and to train the workers of the future. The U.S. has established initiatives for education from K-12 through college with an emphasis on STEM careers. These efforts include programs to inspire students and to help them learn. At the community college level there are programs to train and re-train workers for the jobs of today and tomorrow. Private industry can also help by identifying opportunities and pitfalls for the new workers as they continue their education along the way.[90]

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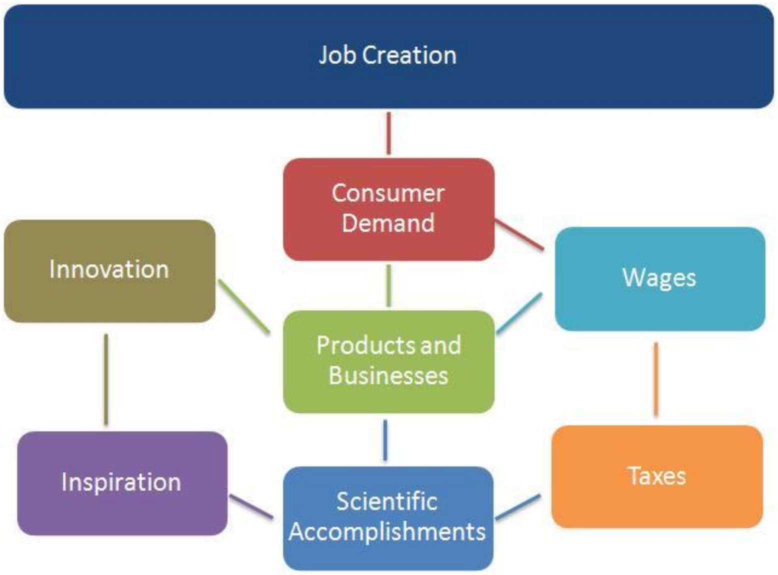
[89] Department of Commerce. Patent Reform Unleashing Innovation, Promoting Economic Growth & Producing High-Paying Jobs. http://www.commerce.gov/sites/default/files/documents/migrated/Patent_Reform-paper.pdf.
[90] Africa at work: Job creation and inclusive growth, McKinsey Global Institute, August 2012.

http://www.mckinsey.com/insights/mgi/research/africa_europe_middle_east/africa_at_work.

Figure 4.16



Web of job creation

There is more to job creation than just the five elements. There is a complex ecosystem that plays a role in job growth. Figure 4.16 shows the factors included in this web of job growth. They include: job creation, consumer demand, scientific accomplishments, innovation, inspiration, wages, and taxes. The economy in the U.S. is mainly based on the amount of consumption there is. One can then reason that when consumer demand increases there will be more jobs that are created. On the other side, when consumer demand falls unemployment rates will start to rise. This can be shown in Figure 4.17:

Figure 4.17

Bloomberg US Weekly Consumer Comfort

This chart compares the Consumer Comfort Index (CCI), in white, against the unemployment rate, in orange, in the US. The CCI is a weekly survey of how comfortable consumers are with the state of the national economy and how willing they are to spend money.

The question then becomes how is it possible to increase consumer demand? In order to increase demand, businesses need to sell products that are both desirable and affordable, and these products are created by innovators. As stated throughout this section, innovation is the key to increase employment. Thomas Edison once said that genius is 1% inspiration and 99% perspiration. Sometimes these inspirational ideas come from past accomplishments in scientific, technological, and engineering fields.

The last two topics of the web are where the businesses, which were built off innovation, contribute back to the society that allowed them to prosper. These contributions come in the form of businesses paying higher wages for their employees as well as the taxes they pay on profits. As employees earn more money, they are more likely to spend more money as well. This is a positive cycle that will help everyone. "The New York Empire State Development Corporation (ESDC), in its own analysis, concludes that for each job directly created, an additional 2.25

"indirect" jobs would ultimately be created."[91] When it comes to taxes, there is a tight rope to be walked. The taxes that are set in place need to be low enough to be competitive so that businesses will want to invest in industries. Yet on the other hand, the taxes will also need to be high enough to support the varying levels of scientific pursuits that generate more innovation

4.2.4 What's Happening Globally?

Global competition is greater than ever. Countries are adopting their own innovation plans. The Information Technology and Innovation Foundation states that, "to be most effective, countries' innovation activity should be found along all matrices of the innovation value chain – in all types of innovation and along all phases of development." What they have found is that most countries have a very narrowly defined view of innovation. Their focus is typically on marketable products traded on international markets for export. For example, the Brazilian government has identified sectors targeted for innovation. These include aerospace, biotechnology, machine tools, pharmaceuticals, and more. Brazil has focused solely on exportable products with no efforts made on domestic products and services. This leaves approximately 80 percent of the opportunities for innovation in services, processes, and business models untouched.[92]

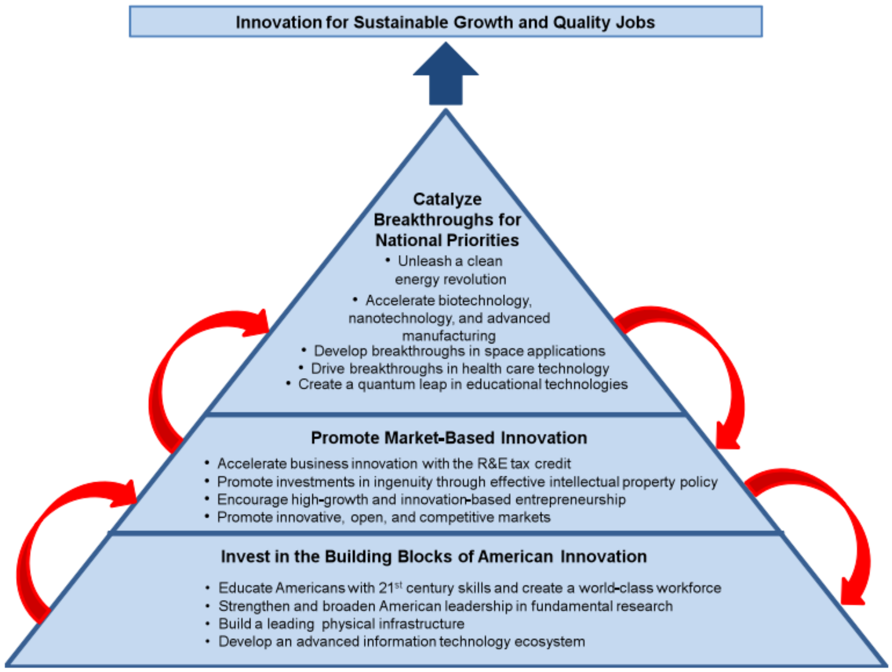
4.2.5 CONDITION OF THE U.S.

The United States has also embarked on its own innovation initiatives. In a paper titled, "A Strategy for American Innovation, Securing Our Economic Growth and Prosperity" the Obama Administration outlines its plans for economic growth and competitiveness. The Administration's plan, updated in February 2011, has several key initiatives; a proposed Wireless Initiative, patent reform, improvements to K-12 education, clean energy, and Startup America. A graphical representation of the Administration's plan can be seen in Figure 4.18:

[91] Fab4x Economic Study. 2006. Everett M. Ehrlich

[92] The Good, The Bad, and The Ugly (and The Self-Destructive) of Innovation Policy: A Policymaker's Guide to Crafting Effective Innovation Policy, The Information Technology & Innovation Foundation, October 2010, Page 16-17.

Figure 4.18



Obama Administration's plan on increasing innovation

The Administration proposes a new Wireless Initiative with the intent to bring high-speed wireless service to 98% of Americans within five years and to create a national public safety network. "This initiative will support advances in security, reliability, and other critical wireless features; accelerate wireless innovations in health, education, transportation, and other application areas; and engage community participation in generating and demonstrating net generation wireless applications."[93] Another key initiative is patent reform. The goal is to increase the quality of patents and to reduce the delay in processing time from 35 to 20 months. "Delay in the granting of [patent] rights has substantial costs. Recent reports conclude that the U.S. backlog (currently at 750,000 applications) could ultimately cost the U.S. economy billions of dollars annually in 'forgone innovation.'"[94] By reducing delays, products will come to market faster, setting the stage for economic growth and high-paying jobs. The new system will allow applicants to fast track the most valuable patents, so they may come to market within one year.

[93] A Strategy For American Innovation, Securing Our Economic Growth and Prosperity, The White House, Page 6.
[94] Department of Commerce. Patent Reform Unleashing Innovation, Promoting Economic Growth & Producing High-Paying Jobs. http://www.commerce.gov/sites/default/files/documents/migrated/Patent_Reform-paper.pdf.

Kindergarten through 12th grade education (K-12) education is also on the agenda. The goal is for every high school student to graduate prepared for college and for a career. To meet this goal, there are several initiatives. First will be the launch of the Advanced Research Projects Agency – Education (ARPA-ED) to research cutting edge technology to enhance learning. Second, funding will continue for school districts undertaking comprehensive reform. The third education initiative entails working in partnership with private groups to inspire more students, especially girls and underrepresented groups, to study STEM fields. There is also the goal of bringing on board an additional 100,000 qualified STEM teachers over the next ten years.

The Administration has proposed a new Clean Energy Standard requiring 80 percent of the nation's electrical power to be derived from clean sources by the year 2035 and a goal of 1 million advanced technology vehicles on the road by 2015. In addition there is proposed funding for research to help reach these goals.

Startup America is the Administration's entrepreneurship initiative. The goal here is to speed the transfer of technology from research to commercialization, provide funding for startups, decrease the regulatory burden and connect entrepreneurs with experienced business mentors.

The new initiatives above will supplement three ongoing areas of effort; investment in the building blocks of American innovation, promotion of market-based innovation, and catalyze breakthroughs for national priorities.

Investing in the building blocks of innovation has four main topics. First is to educate and to train a world-class workforce. To improve the education system from early childhood to college, the Obama Administration is supporting age appropriate programs to inspire and promote students in STEM fields, to improve the affordability of colleges, to make investments in community colleges, and to use public-private partnerships to train workers for 21st century jobs. Second, the Administration is increasing funding for basic research at the National Science Foundation, the Department of Energy's Office of Science, and the National Institute of Standards and Technology laboratories. Third, the Administration wants to build a 21st century infrastructure with improvements to roads, railroads, and airports and new investments in high-speed rail, next generation air traffic control, and a National Infrastructure Bank. The fourth initiative is in information technology with expanded internet access, a modern electric grid, increase wireless spectrum, and secure cyberspace.

To promote market-based innovation, the Administration has proposed for the Research and Experimentation Tax Credit to be made permanent. In support of innovative entrepreneurs, the Administration has expanded programs to lend money and provided tax credits for small business. To catalyze innovation hubs, the Administration is looking to bring together scientists and entrepreneurs to support innovation. They will also promote open markets and free trade agreements.

The Administration has defined certain "National Priorities" that are key to future innovation. These include alternative sources of clean, renewable energy, and technology to lower the cost and delivery of quality healthcare services. The National Institutes of Health and The National Nanotechnology Initiative are providing funding for advanced research in biotechnology, and nanotechnology. NASA and the Department of Defense are working on the development of space capabilities for communications, navigation, commerce, and security. The Department of Education is supporting research on new technologies to improve learning and train workers."[95]

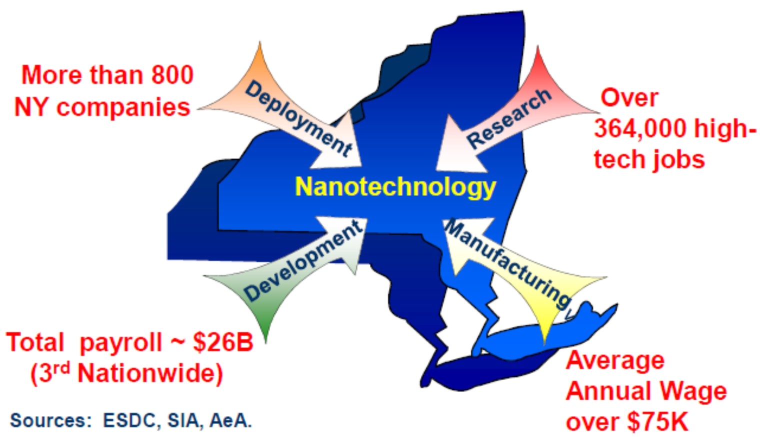
4.2.6 WHEN INNOVATION MEETS JOB CREATION

What happens when investments in innovation and new technologies combine with a well-developed job creation strategy? In the early 1990s, New York State found itself losing manufacturing jobs statewide. Steel mills were closing; large employers such as Xerox, Kodak, and General Electric were either downsizing or moving out of the state altogether. In 1993, former Governor Mario Cuomo provided $10 million of financing for a Materials Physics Program designated as a Center for Advanced Technology (CAT) in Albany, New York. With nanotechnology as a focus, this program was to conduct cutting-edge research on next generation computer chip technologies. This began New York State's Nanotechnology Initiative. In 1997, the NanoFab 200 building was built and in 1998 the Semiconductor Industry Association (SIA) established a National Focus Center Consortium. IBM followed in 2001 by deciding to build their Nanoelectronics Center of Excellence with a group of partners. Over the next several years, a number of companies have established a presence in the area leading to the establishment of the School of Nanosciences and Nanoengineering at the University at Albany in 2001. This later became the College of Nanoscale Science and Engineering (CSNE) of the University at Albany

[95] A Strategy for American Innovation, Securing Our Economic Growth and Prosperity, The White House, Page 1-7.

in 2004. Once the college was established, other organizations such as Applied Materials, Micron, AMD, Infineon, Vistec, and a NIST/Army partnership came to Albany. Today, CNSE's Albany NanoTech Complex is one of the world's leading research centers with over $14 billion in investments innovation. The center is home to more than 2,700 engineers, faculty, researchers, scientists and students from firms such as IBM, Intel, GlobalFoundries, SEMATECH, Samsung, TSMS, Toshiba, Applied Materials, Tokyo Electron, ASML, and Novellus Systems. The effects of the Nano Initiative can be shown in the Figure 4.19:

Figure 4.19



Effects on New York State from the Nano Initiative

The Public-Private Partnership:

In his presentation on "Growing Innovation Clusters for American Prosperity", Pradeep Haldar spoke of breaking down "silos" and departmental structures to create groups of engineers and business people who could work and communicate easily with each other. Since most of the people hired were from industry and not academia, they already knew what was needed to make this initiative attractive to industry. CSNE's approach was to partner with industry and break down barriers. Instead of doing research and trying to license it, companies would give the college money in return for research. [96]

[96] Pradeep Haldar, Presentation at June 3, 2009, National Academies Symposium on "Growing Innovation Clusters for American Prosperity."

The success of New York's Nano Initiative can be attributed to the center of excellence model and creation of the CNSE. The cluster brings together the innovative research of the universities and the companies that need to make money. The activities they undertake include business incubation, pilot prototyping, and test bed integration. Haldar continued to say that, "we do the entire gamut of what's of interest to these companies."[97] This includes creating partnerships with community colleges, with K-12 schools, construction trades training, high school and undergraduate internships, equipment supplier training, and institutes in order to develop the workforce that is a key component in the semiconductor industry.

Haldar explained how the objective for the regional cluster was to make it a global powerhouse. There was a vision held by the governor and industry leaders that they could create an "industry cluster". Companies from Asia and other places came to make large investments in all types of semiconductor technologies. Their target markets include the energy industry, wireless communications, automotive, aerospace, sensors, bio-health, defense, and green technology.[98]

The largest success to date has been the construction of the GlobalFoundries semiconductor foundry manufacturing facility in Saratoga County, New York. Originally conceived by AMD and New York State in 2006, ownership was transferred to a joint venture between a new company, GlobalFoundries and the Advanced Technologies Investment Corporation (ATIC) of Abu Dhabi, U.A.E who invested over $4 billion in the project. New York State offered $1.2 billion in incentives to induce AMD to locate the facility in Saratoga County. It is important to note that according to the Semiconductor Industry Association, it costs about a billion dollars more to build a facility of this type in the United States than it does in other parts of the world. Without the state's incentive package, this project would not have been built.[99]

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[97] Pradeep Haldar, Presentation at June 3, 2009, National Academies Symposium on "Growing Innovation Clusters for American Prosperity."

[98] Pradeep Haldar, Presentation at June 3, 2009, National Academies Symposium on "Growing Innovation Clusters for American Prosperity, Pages 61-64, http://www.nap.edu/catalog.php?record_id=12926.

[99]Manufacturing, Competitiveness and Technological Leadership in the Semiconductor Industry - An assessment of the economic impacts of the proposed joint venture project of AMD and the Advanced Technologies Investment Corporation to build and operate the Fab 4X semiconductor foundry manufacturing project in Saratoga County, New York, Everett M. Ehrlich, President, ESC Company. http://lutherforest.org/pdfs/Fab4xEconomicStudy.pdf.

In October 2008, GlobalFoundries began construction of the world's most advanced semiconductor fabrication facility in "Tech Valley". Tech Valley is the name given to the regional cluster that extends from New York City to Canada. New York's goal was to build this nanotechnology cluster in order to increase economic development in the region and in the state. The facility, now known as Fab8, has surpassed all of the original expectations. Key suppliers of engineering services, manufacturers of equipment, construction firms, etc. are moving to the area to be near the facility. Since beginning construction, GlobalFoundries has already announced an expansion of the manufacturing facility, an additional office building, a manufacturing test, and an automation laboratory. In January 2013, GlobalFoundries filed an application with the town of Malta, New York to begin the process of determining the feasibility of building a $10 billion fabrication facility at the site.[100] GlobalFoundries decision to locate in Saratoga County was based on three reasons; education, economics, and ecosystem. There are several world class research universities in upstate New York. These include Rensselaer Polytechnic Institute, the College of Nanoscale Science at SUNYAlbany, Colgate, Clarkson, and Cornell. In addition Hudson Valley Community College with funding from New York State established TEC-SMART (Training and Education Center for Semiconductor Manufacturing and Alternative and Renewable Technologies). TEC-SMART is a workforce training facility within walking distance of Fab8. The economics portion consisted of the $1.2 billion of incentives from the state.

The "ecosystem" or "cluster" of educational institutions, high-tech businesses, and skilled workforce in Tech Valley has grown to over 250 companies with over $15 billion invested. Some examples of businesses moving to the region because of Fab8[101] include: M+W Group, Inc., FALA Technologies, KLA-Tencor, Tokyo Electron, and Air Liquide. M+W Group, Inc. is a world leader in engineering and construction of semiconductor facilities moved their headquarters to the area. FALA Technologies is a developer of precision machines in Kingston, New York Air Liquide is a French gas company.

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[100] From The Business Review: http://www.bizjournals.com/albany/new/2013/01/28/globalfoundries-laying-groundwork-for.html.

[101] A Study of the Economic Impact of GlobalFoundries, Everett M. Ehrlich, President, ESC Company. http://lutherforest.org/documents/EhrilchEconomicStudyUpdateJune2011.pdf.

4.2.7 THE PUBLIC-PRIVATE PARTNERSHIP

"At the nanotechnology college, he said, one of the main strategies was to "break silos" and bypass ordinary departmental categories in favor of constellations of engineering and business people who could communicate easily. "Our model differs from traditional university setting," he said. "Since we built from ground up, 70 percent to 80 percent of the people we hired came from industry, so they know what industry needs. Academics do good basic research, but in the future, universities are being forced to deliver for companies in exchange for support. The traditional model—do the research, throw it over the fence, try to license it—will not work." CNSE does not rely on a tech transfer office, he said, which seldom produce income. "That's a barrier we've broken down," he said. "Instead, we partner with our industry and figure out ways to break down IP barriers. We're not trying to make money at the college—the companies give us money in return for the research we do."[102]

The success of New York's Nano Initiative can be attributed to the center of excellence model and creation of the CNSE. The cluster brings together the innovative research of the universities and the companies need to make money. The activities they undertake include business incubation, pilot prototyping, and test bed integration. "We do the entire gamut of what's of interest to these companies. Workforce development is a key component, including partnerships with community colleges, with K-12 schools, construction trades training, high school and undergraduate internships, equipment supplier training, and institutes to develop the semiconductor workforce."[103]

The planner's objective for the regional cluster was to make it a global powerhouse. "Our governor and industry leaders saw the vision of creating a real key gateway for industry clustering," he said. "We had companies from all over, including Asia, come to work here. We have huge investments in a range of semiconductor technologies and we are looking at deploying them into every sector, including energy, wireless communications, automotive, aerospace,

[102] Pradeep Haldar, Presentation at June 3, 2009, National Academies Symposium on "Growing Innovation Clusters for American Prosperity."
[103] Pradeep Haldar, Presentation at June 3, 2009, National Academies Symposium on "Growing Innovation Clusters for American Prosperity."

sensors, bio-health, and defense. Right now, we're again in partnership with New York State to create clusters for green technology jobs. The applications of nanotechnology are just huge."[104]

The largest success to date has been the construction of the GlobalFoundries semiconductor foundry manufacturing facility in Saratoga County, New York. Originally conceived by AMD and New York State in 2006, ownership was transferred to a joint venture between a new company, GlobalFoundries and the Advanced Technologies Investment Corporation (ATIC) of Abu Dhabi, U.A.E who invested over $4 billion in the project. New York State offered $1.2 billion in incentives to induce AMD to locate the facility in Saratoga County. It's important to note that according to the Semiconductor Industry Association, it costs about a billion dollars more to build a facility of this type in the United States than it does in other parts of the world. Without the state's incentive package, this project would not have been built.[105]

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[104] Pradeep Haldar, Presentation at June 3, 2009, National Academies Symposium on "Growing Innovation Clusters for American Prosperity, Pages 61-64, http://www.nap.edu/catalog.php?record_id=12926.

[105]Manufacturing, Competitiveness and Technological Leadership in the Semiconductor Industry - An assessment of the economic impacts of the proposed joint venture project of AMD and the Advanced Technologies Investment Corporation to build and operate the Fab 4X semiconductor foundry manufacturing project in Saratoga County, New York, Everett M. Ehrlich, President, ESC Company. http://lutherforest.org/pdfs/Fab4xEconomicStudy.pdf.

[106] From The Business Review: http://www.bizjournals.com/albany/new/2013/01/28/globalfoundries-laying-groundwork-for.html.

research universities in upstate New York. These include Rensselaer Polytechnic Institute, the College of Nanoscale Science at SUNYAlbany, Colgate, Clarkson, and Cornell. In addition, Hudson Valley Community College with funding from New York State has established TEC-SMART (Training and Education Center for Semiconductor Manufacturing and Alternative and Renewable Technologies). TEC-SMART is a workforce training facility within walking distance of Fab8. The economics portion consisted of the $1.2 billion of incentives from the state.

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4.2.8 JOB CREATION

When the Fab8 project was originally planned, AMD committed to hire a minimum of 1,205 full-time employees at the facility by the beginning of 2014. Approximately 30 percent of the Fab8 employees are expected to be engineers with bachelors or advanced degrees in electrical engineering, physics, chemistry, or mathematics. Table 4.2.5 below shows the expected number of jobs created and the associated increase in payroll in the region.

[107] *A Study of the Economic Impact of GlobalFoundries*, Everett M. Ehrlich, President, ESC Company. http://lutherforest.org/documents/EhrilchEconomicStudyUpdateJune2011.pdf.

Permanent Jobs	Annual	Average Salary	Annual Payroll
GlobalFoundaries full time employees	1.465	$60,000	$88 million
On-site services	550	$40,000	$22 million
Indirect jobs	4,500	$40,000	$180 million
Total payroll from operations	6,500		$290 million
Temporary Construction Jobs			
Construction Jobs	1,000	$64,000	$62 million
Indirect construction related jobs	1,700	$40,000	$68 million

4.2.9 CONCLUSIONS

If the United States is to be successful in creating jobs for scientists and engineers it has to compete and prosper in the 21st century and beyond. Knowing what to do is not the problem. Having the "will" as a nation is the challenge. History has shown that innovation is the key to competitive advantage and to greater prosperity. This is no secret. Nations throughout the world are instituting programs and policies to position themselves to compete in the global economy.

Improvements in K-12 science and mathematics education will position students for greater success in college. One of the most fundamental changes needed is to improve the quality of science and mathematics teachers particularly in lower income communities. At the high school level, more challenging coursework is needed. Students taking advanced placement courses are more successful than those who do not.

Support for basic science and engineering research is critical to the country's future growth and prosperity. Many of the greatest advances of the last century were the result of basic research carried out at government laboratories, research universities, and private organizations. Products that are taken for granted every day are the result of some of the most basic research.

The transistor, biotechnology, and nanotechnology are all products of fundamental research. Government funding for basic research is inadequate at current levels.

Proportionately fewer students in the United States study science and engineering in college than students in other nations. This will create a significant shortfall in scientists and engineers in the United States over the next twenty years due to older scientists and engineers retiring. As minorities represent an ever increasing percentage of the population, these groups need to increase their interest in a STEM education. Immigration policies will also need to be addressed so the best and brightest foreign students can stay in the U.S. and live and work here.

Incentives for innovation make it desirable for entrepreneurs, inventors, and investors to work here and build their businesses here. Stronger intellectual property protection, research and development tax credits, and expanded access to the internet have all been identified as ways to increase incentives for innovation.

Once the groundwork for innovation has been laid, the next focus is job creation. From a policy perspective, there are five elements to job creation. The first is to identify labor intensive subsectors where there is a global competitive advantage or strong domestic demand. Second is to improve access to capital for those sectors and to incentivize banks to increase lending, to allow foreign investment, and to educate new borrowers. Third is to build suitable infrastructure to support those sectors and the regions they are in. This is where clustering has proven to be so successful. Fourth is to cut unnecessary regulation, bureaucracy and corruption. The process of building a business needs to be simplified to reduce time and expense. Finally, there must be public and private cooperation and buy-in to provide a suitable workforce with the education and technical skills needed for jobs in those sectors.

4.3 TECHNOLOGY

The technology section will discuss various topics in technology from the past and present. It discusses research institutions, government funding, and technology in schools. A few of the research institutions looked at include MIT's Lincoln Laboratory, University of California Berkley, University College London, and the University of Cambridge. These universities were chosen as a result of their clout and relevance to technology and research.

4.3.1 SUMMARY

Technology exists as an essential entity in the everyday lives of Americans. It prevails not only in personal lives, but also in academic and professional lives. Technological research provides many opportunities for students and is arguably essential for the survival of the US as a nation.

A term heard occasionally is "technological determinism". This is used to represent the idea that technology drives society. In other words, the technology available determines what type of society we are. While this may initially appear true, it also appears that the converse is true: society drives technology. A good example is wireless technology. People today are always on the move, so a telephone that is not tethered to anything is highly desirable. This is evident in the fact that there were only 34 million mobile cellular subscribers in 1993 but there are now 4 billion subscribers, as of the end of 2008[108]. It was this desire to be mobile that encouraged the development and production of high capacity cellular towers. As a result of this available and easily accessible technology, society as a whole became more mobile.

While technology is an important part of everyday lives, great care must be taken not to let it own society. The term "technological somnambulism", first used by Langdon Winner in his essay "Technology as forms of life", is used to describe the idea that people are simply in a vegetated state of sleepwalking when it comes to their technology. Although written over 100 years ago, "The Machine Stops" by E.M. Forster is an interesting science fiction short story that pokes fun at exactly this concept. "The Machine is much, but it is not everything."[109] In "The Machine Stops", the people are dependent on this machine, which no one knows how it works. When the machine suddenly stops working, nobody can fix it and the civilization eventually collapses as a result. While the group does not feel that something of that magnitude will happen to humanity anytime soon, it is an idea that should be entertained in moderation as computers continue to become stronger, smarter, and more powerful.

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108 Kurose, James F., and Keith W. Ross. "Chapter 6 - Wireless and Mobile Networks." Computer Networking: A Top-down Approach. Boston: Pearson/Addison Wesley, 2008. 523. Print.

[109] Forster, E. M. The Machine Stops. London: Penguin, 2011. Print.

4.3.2 MOTIVATION OF RESEARCH

The United States has established itself as a major pioneer of various technological fields. There have been various driving forces behind this, one of which is defense. The US is undoubtedly a very powerful nation and often the target of various extremist groups and other nations. A few examples of this, which will be explained in more detail, are the USS Maine, the Space Race, and ARPANET. These events were tied tightly to national security and the end product of these events was a more secure nation.

There are certain aspects of technology that have remained without question for many years. “Remember the Maine!” was the battle-cry of the US armed forces in the late 1800s. The USS Maine was a battleship that suddenly exploded in February of 1898. Although it did not directly cause the Spanish-American War, it prevented peace talks with Spain which eventually led to the aforementioned war. As a result of this war, an excise tax was placed on long-distance phone calls. This tax remained for over 100 years until it was repealed in 2006[110].

The Space Race was a period of competitive space exploration between the United States and the Soviet Union (USSR - Union of Soviet Socialist Republics). The “race” lasted from October 1957 to July of 1975. The Space Race was provoked by the Cold War, characterized by a heightened state of tension between the US and the USSR. The US passed the National Defense Education Act of 1958 to keep the US competitive and safe. As a result of this investment, the US discovered many useful technological devices, along with sending astronauts to the moon.

The Internet is essential for communication in today's society. Back in 1969, Advanced Research Projects Agency Network (ARPANET) was established as the first packet switched network. A packet switched network allows Internet data (packets) to be segmented and transmitted without actually knowing the destination ahead of time. This is in contrast to circuit switched networks, which require circuits to be connected before data transmission begins, which is the technology that early analog telephone networks used. The advantage of this packet switched network was that resources were allocated on demand and could be used to increase connection throughput (rate of data successfully transferred). Although it is a misinterpreted, many people believe that ARPANET was created to withstand a nuclear war, so that

[110] Reardon, Marguerite (August 1, 2006). "Telecom tax imposed in 1898 finally ends". CNET Networks. Retrieved 2012-11-01.

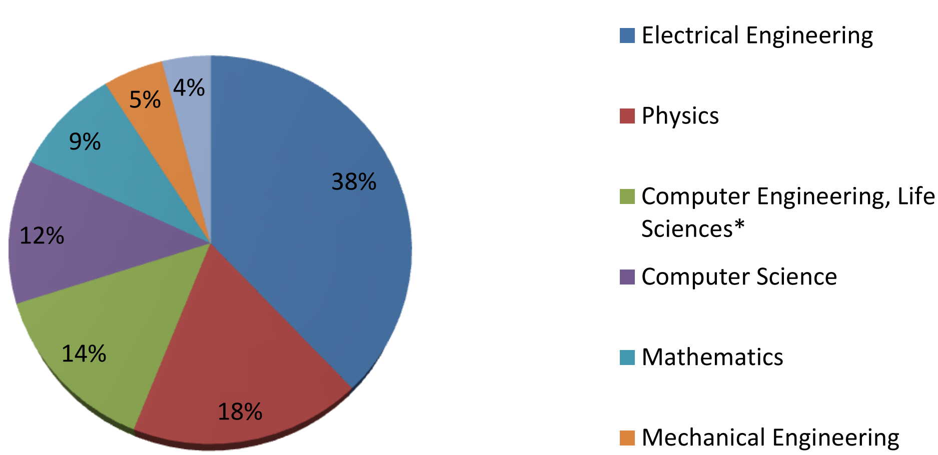
communication could still take place. Either way, ARPANET was funded by the Department of Defense and became the all-important backbone of the Internet.

4.3.3 RESEARCH INSTITUTIONS

Research Institutions are a staple of US research and innovation. The provide highly educated and distinguished staff as well as plenty of computing machinery and various technologies. Many research institutions get a majority of their funding from the government, rather than from the private sector. Possible motivation for this could be because the research that is done at these universities would be for the betterment of society as a whole, rather than just to financially benefit the backing company.

MIT Lincoln Laboratory in Lexington, MA is a major research center funded by the Department of Defense (DoD). As it is backed by the DoD, much of the research is focused on areas that directly affect national security. Here is the breakdown of their professional staff[111]:

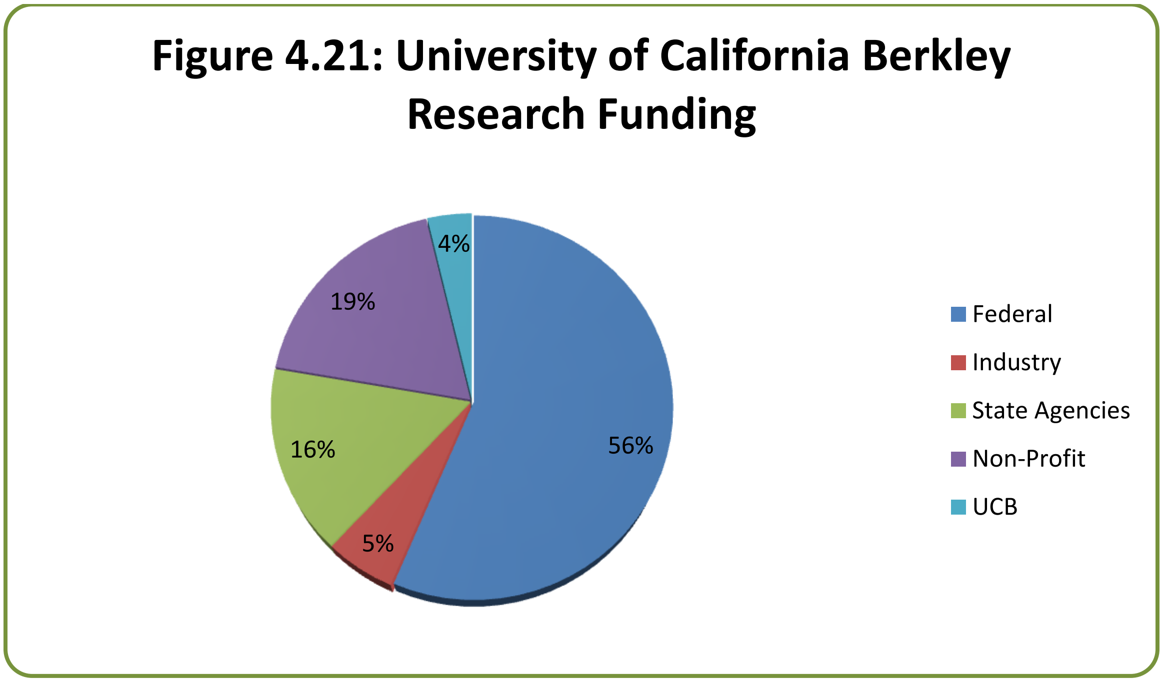
Figure 4.20: MIT Lincoln Laboratory Profile of Professional Staff



As you can see, the majority of the staff focuses on electrical engineering and physics. The machines developed here can be used in a variety of ways, such as search and rescue missions.

[111] http://www.ll.mit.edu/about/2011_Facts_Book.pdf – 2011 MIT Lincoln Labs Facts Book

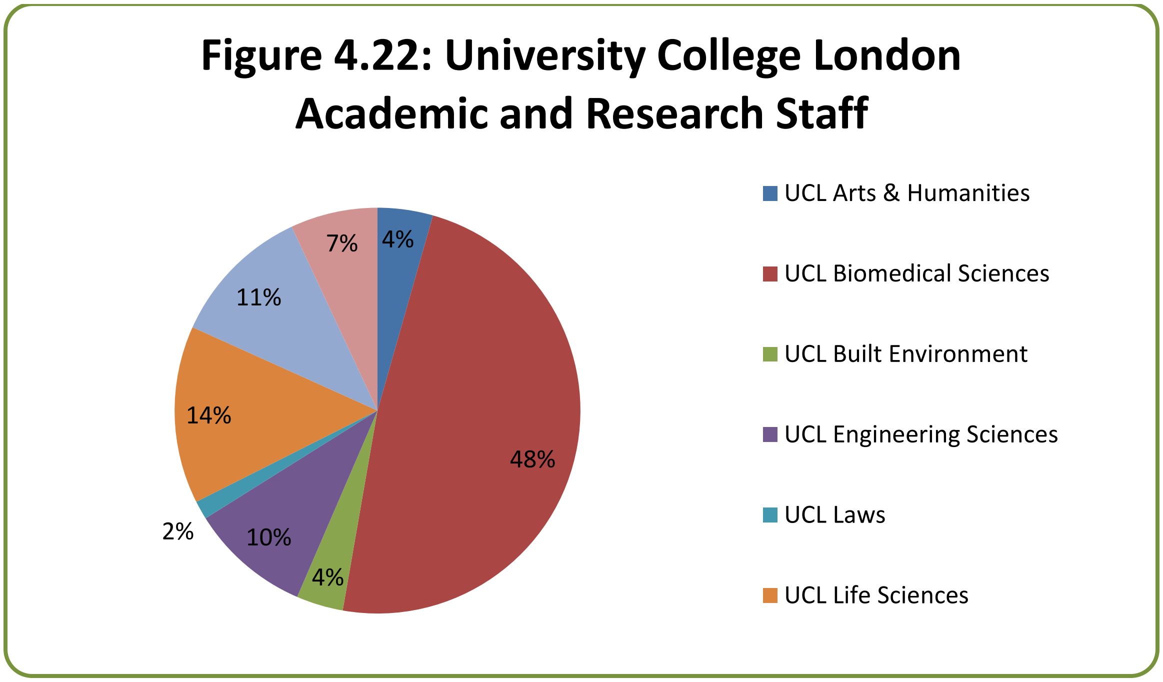
The University of California at Berkeley is a research university located in Berkeley, CA. The university is backed by the Department of Health and Human Services and the National Science Foundation. The funding received by the university comes mostly from the government[112]:



University of California Berkeley obtains the majority of its funding from the government and state agencies. The industry and the university itself accounts for less than 10% of the total funding.

While we seem to be more focused on technology here in the US, colleges in London don't seem to share our love of technology. The University College of London tends to focus more on life science such as biology[113].

[112] http://vcresearch.berkeley.edu/sites/all/files/wysiwyg/filemanager/Berkeley_in_Numbers_FY2012_-_Sep_4_2012-1.pdf – UCal Berkley Fiscal Year 2012
[113] http://www.ucl.ac.uk/research/excellence – University of College London Academic and Research Staff



As the figure suggests, bio-medical science is the main focus of the university. More emphasis is placed on life sciences, law, art, and social sciences. There is far less emphasis on engineering than in many US research institutions.

When talking about research institution funding, there is fundamentally not much difference between the US and the UK, as much of the funding still comes from the government. The UK has a governing body set up to provide funding to universities for research. The UK Research Councils consists of 7 specialized departments focusing on:

- Arts and Humanities
- Biotechnology and Biological Sciences
- Engineering and Physical Sciences
- Economic and Social
- Medical
- Natural Environment
- Science and Technology

The Research Councils are considered to be a non-departmental public body, which means that it is not an essential part of the government. They are accountable to Parliament and enjoy more economic freedom than other branches. Here are the financial breakdowns for the University of Cambridge[114] and the University College London[115].

Figure 4.23: University of Cambridge Funding

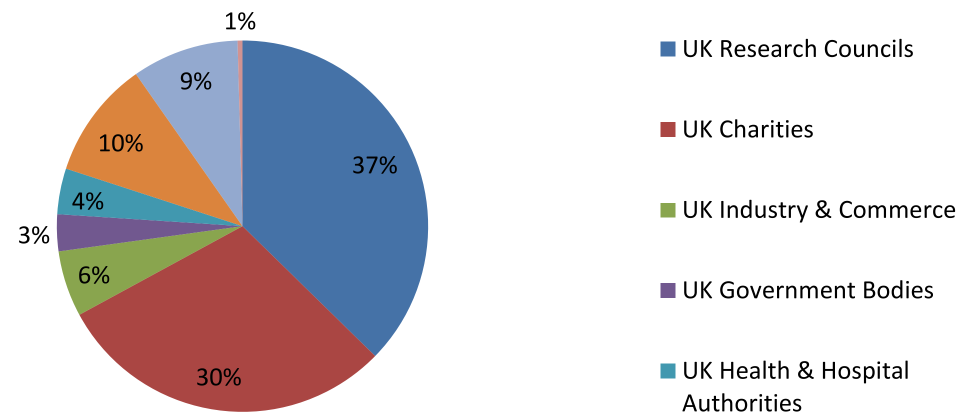
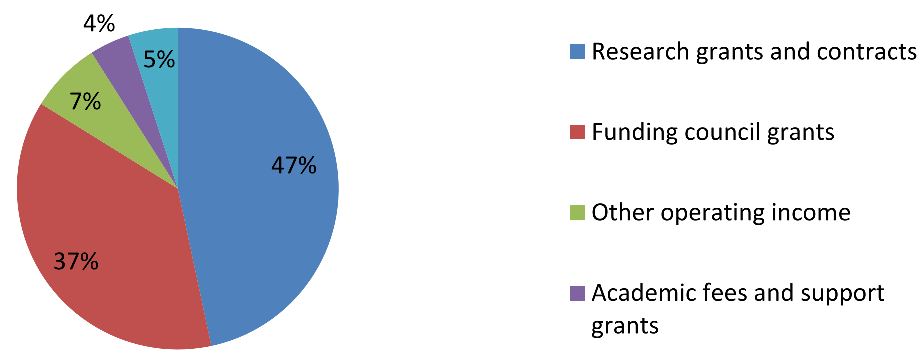


Figure 4.24: University College London Funding



As the data shows, the majority of the funding comes from the UK Research Council. Much like the US, very little income comes from private companies and the universities themselves.

[114] http://www.cam.ac.uk/research/about/research-income/ - University of Cambridge FY2010
[115] http://www.ucl.ac.uk/research/excellence – University College of London 2009/10

4.3.4 FUTURE DIRECTIONS

Most of the research done was to see how useful technology is to the United States in its quest to remain on top globally. While research statistics and investments are good indicators, they are not always completely accurate. Areas that could help to fill gaps would be to look at a selected few specific inventions or patents. This would allow us to see how specific pieces of technology have helped and impacted the United States. This would help when looking at schools that are granted large sums of money vs. schools that are not. It is entirely possible that schools that get very little money actually produce pieces of technology, perhaps by chance, that bring in more money or have a larger impact than expected. Looking closer at cases like this would allow for the speculation of research that produces quality results rather than quantity results.

4.3.5 RESULTS

Technology is not only a tool, but also a research topic. Further research allows us to develop technology which in turn allows us to do everyday tasks faster and more precisely. Many pieces of technology that allow us to do this have been developed at various research universities. The government is usually the major backing factor for many of these universities. Although some people may see this as a waste, it is actually an intelligent decision. This methodology produces a bi-directional relationship between the universities and the government in the following manner:

1. Government provides funding to universities
2. Universities develop useful state-of-the-art technology
3. Government uses the technology for national defense, monetary gain, etc.
4. Government uses monetary gain to repeat step 1

This cycle is very important to the United States economy and education. It provides education and jobs for motivated individuals, while also producing useful and marketable technology. To withhold funding for research institutions would drastically prevent the US from continuing to be a driving global force.

4.3.6 CONCLUSIONS

Technology is a vast topic with many strings. Pulling one string may help one person, or group of people while hindering another. This means the United States must take a balanced approach towards technology in the workplace and in schools. Too much focus will alienate other fields while too little focus will prevent new developments. There is an apparent cycle involving the government, schools, and private sector when it comes to standard technology research:

1. Government invests in technology research institutions
2. Research institution yield discovery
3. Private sector companies market new ideas based on this technology

This seemingly simple process yields many jobs and opportunities for a wide range of people. It raises a need for talented and skilled individuals who are trained in the specific technological disciple. It also creates jobs in the private sector for these skilled engineers. For this reason, government investment is essential to the further development of technology. These investments will also indirectly create jobs.

Today's economy is a vast and complex entity. One factor prevalent in the status of the economy is new ideas. “Research sows the seeds of innovation”[116] New and exciting ideas help to fuel the economy. It brings opportunities for students, potential employees, and investors/venture capitalists. Currently, the majority of research is focused on yielding short term results, mostly financial profit. Long-term research is daunting at first, but has been shown to yield worthy results. This is much easier said than done, due to the pressure and nature of today's financial market. If long-term investments were made easier, there would be more potential for technological opportunities.

It is also worth noting things that nations cannot easily change: population. For example, 1 US assembly worker. can be employed for the same price as 20 Vietnam workers. From a business standpoint, this is an attractive area to cut costs. From a manufacturing point-of-view, it would be very difficult for the United States to match other nations in terms of quantity. What can be done, however, is utilizing the quality of workers. If the United States can produce quality

[116] Rising above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future. Washington, D.C.: National Academies, 2007

engineers, they will be more valuable to any organization or company. By educating new students with the best and brightest professors, the United States can produce some of the world's most intelligent and valuable engineers.

History has shown that various research institutions and projects have yielded some of the most important technological breakthroughs. These institutions and their efforts would not have been possible without the investment of the government. These achievements were the result of many educated and motivated engineers, backed with the financial support of their institutions and government. To continue to be a global presence in technology, the United States needs to continue its record of outstanding academic research.

4.4 POLITICAL

There is no denying that America is one of many players in the realm of science and technology (S&T) on a global scale. It is worthwhile to compare America with some of the most well-known scientific nations, such as Germany, and some of the up-and-coming nations, like India. Doing so will allow us to see what these nations do right and what they do wrong, providing valuable knowledge regarding ways in which America can help improve its global competitiveness in an era where science is becoming increasingly important. Two of the selected nations are considered to be developing nations: the People's Republic of China and the Republic of India. Although both nations are based on different political systems and have different histories which have affected the development of their respective political systems, they are growing at a truly rapid pace and are quickly catching up with the United States. In fact, some projections, such as the one made by Goldman Sachs, show that the economies of these two nations, along with Brazil and Russia, will together overtake the leading world economies (the United States, Japan, the United Kingdom, Germany, France, and Italy) by no later than 2040.[117] Three developed nations have also been selected for review: Japan, the Federal Republic of Germany, and the United Kingdom. These nations are some of the top producers of science in the world and are working to maintain their position as global leaders of science. What has brought these nations to the top and what is fueling the rise of developing nations in global science and engineering? There are many factors that affect the economy of a nation, especially

[117] Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future. National Academy of Sciences, National Academy of Engineering, and Institute of Medicine. 2007.

in an economy that is becoming increasingly globalized, but there is no doubt that science, technology, and engineering all play significant roles in the growth, and consequently, the decline, of nations as a whole. Scientific advancements give rise to new technology, which engineers find new ways to use in a country's infrastructure and in our lives. The nations will be compared on the basis of their spending on science, their science policies, their capacity to perform research, their output of scientific literature, and their STEM education systems.

4.4.1 RESEARCH AND DEVELOPMENT EXPENDITURE

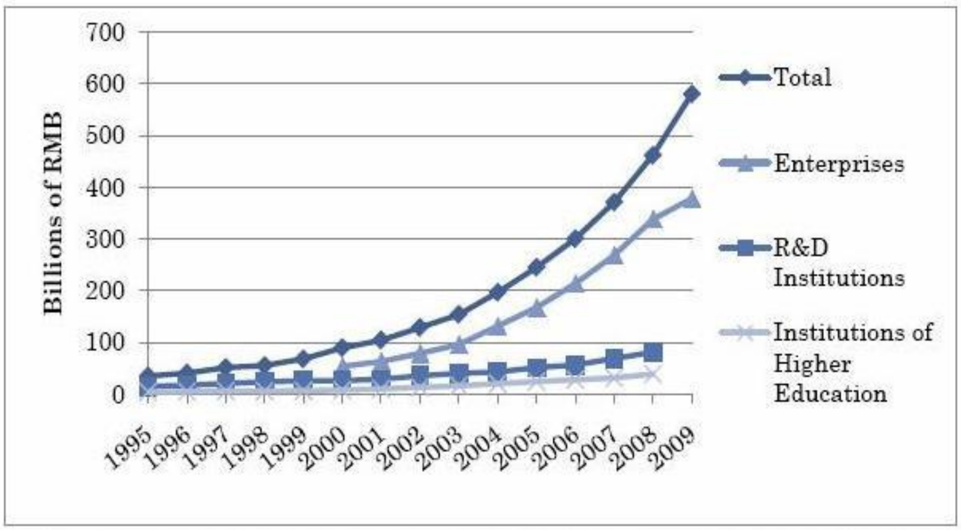
The United States spent $148 billion in 2011 on research and development (R&D), corresponding to roughly 2.7% of the nation's annual GDP.[118] In fact, the nation accounts for nearly 40% of all R&D spending in the world[119], a significant portion of which is defense R&D. However, this global share is falling. From 2008 to 2010, the percentage of global R&D spending that was made up by the US fell from 35.4% to 34.4%. Since then, it has continued to drop to 31.1%, where it remains today[120]. The amount that the United States spends annually on R&D, as a percentage of its GDP, has seen little change over the last six years, hovering around 2.8% in the last three years[121], or roughly $425 billion each year. A majority of R&D financing in the US comes from industry sources, which were responsible for 67% of all R&D expenditure during 2007. In the same year, federal spending contributed 27% to the total R&D expenditure.[122]

China's R&D spending has been on the rise over the last decade, with its expenditure as a percent of GDP having grown by a factor of six. The figure has taken an astounding leap from just 0.6% in 1995 to 1.6% in 2011[123]. Just between the years 2000 and 2008, Chinese expenditure on R&D increased from $10.8 billion to $66.5 billion, bringing with it an average growth rate of 22.8% per year. Although the increase seems to be slowing, having risen from 1.48% in 2010 to 1.6% in 2012[124], Chinese progress seems to nevertheless be certain for the

[118] Introduction to the Federal Budget. Patrick Clemins. American Association for the Advancement of Science. 2010.
[119] Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future. National Academy of Sciences, National Academy of Engineering, and Institute of Medicine. 2007.
[120] 2012 Global R&D Funding Forecast. Battelle. 2011
[121] 2012 Global R&D Funding Forecast. Battelle. 2011.
[122] UNESCO Science Report 2010. UNESCO. 2010.
[123] 2012 Global R&D Funding Forecast. Battelle. 2011
[124] 2012 Global R&D Funding Forecast. Battelle. 2011.

future. In fact, despite the slowing climb of its funding, China's global share of R&D spending is still on an impressive rise, growing from 9.1% in 2008 to 12.3% in 2010.[125] This further rose to 14.2% in 2012.[126] However, the intensity of China's R&D still lags behind most other developed nations. A great deal of China's R&D expenditure goes towards experimental development (83% of total expenditure[127]) while basic research receives only a small portion of all funding (5% of total expenditure[128]). Almost 70% of all R&D spending comes from industry sources.[129]

Figure 4.25[130]



[18] National Bureau of Statistics, Ministry of Science and Technology. *China Statistical Yearbook on Science and Technology: 2009* (Beijing: China Statistics Press, 2009), statistical data CD, Section 1-9;

Overall Chinese R&D Spending and R&D Conducted by Performer (1 RMB = 0.16 USD)

Most of this funding predictably funds industry-based projects. The amount that industry contributes to funding R&D in China has been increasing. In 2000, industry funded 59.95% of

[125] UNESCO Science Report 2010. UNESCO. 2010.
[126] 2012 Global R&D Funding Forecast. Battelle. 2011.
[127] UNESCO Science Report 2010. UNESCO. 2010.
[128] UNESCO Science Report 2010. UNESCO. 2010.
[129] China's Program for Science and Technology Modernization: Implications for American Competitiveness. Micah Springut, Stephen Schlaikjer, David Chen. 2011.
[130] China's Program for Science and Technology Modernization: Implications for American Competitiveness. Micah Springut, Stephen Schlaikjer, David Chen. 2011.

all R&D in China. By 2008, this figure was 73.26%, signaling a growing interest in China by private industry.[131]

Although R&D spending in India is on a generally increasing trend, the country still spends far less compared to other countries with a significant science presence globally. In 2002, India had invested $3.7 billion in its R&D sector, in stark contrast with the $15.5 billion, $124 billion, and $277 billion invested by China, Japan, and the United States, respectively.[132] Annually, India spends roughly 0.8% of its GDP on R&D, a figure which over the years has remained stagnant.[133] In 2010, India spent $32.5 billion on R&D, which increased to $41.3 billion in 2012.[134] Furthermore, the nation's share of global R&D expenditure has remained steady, having barely increased from 2.6% in 2010 to 2.9% in 2012.[135] A sizable portion of India's R&D funding goes towards its research institutes. Indian universities receive a small share of all funding and, as such, play a smaller role in Indian research. The government accounts for nearly two-thirds of R&D expenditure in the country. Higher education accounts for only a small fraction - approximately 5%, of this amount. Industry does not yet fund a significant majority of R&D in India, though the trend is beginning to shift. Although R&D expenditure in India had only increased from 0.8% to 0.88% between 2003 and 2007, the share of this expenditure funded by industry leapt from 18% to 28%.[136] Additionally, foreign direct investment (FDI) has grown from an amount of $2 million in 1993 to $19 billion in 2009.[137]

Each year, Germany spends roughly 2.5% of its GDP on R&D, a number that continues to rise. German R&D expenditure as a percentage of GDP increased from 2.82% in 2010 to 2.87% in 2012.[138] This expenditure is high compared to other nations in the European Union (EU); in 2007, it had the highest R&D expenditure of any EU nation.[139] Germany has set a goal of spending 3% of its GDP annually on R&D in an effort to keep up with other quickly developing nations. The majority of Germany's R&D expenditure is funded by industry sources,

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131 UNESCO Science Report 2010. UNESCO. 2010.

132 "India lagging in science and technology, says official". T.V. Padma. SciDev.Net. August 29, 2006. http://www.scidev.net/en/new-technologies/space-technology/news/india-lagging-in-science-and-technology-says-offi.html

133 Science, Technology, and the Economy: An Indian Perspective. Roddam Narasimha. Jawaharlal Nehru Centre for Advanced Scientific Research. 2008.

134 2012 Global R&D Funding Forecast. Battelle. 2011.

135 2012 Global R&D Funding Forecast. Battelle. 2011.

136 UNESCO Science Report 2010. UNESCO. 2010.

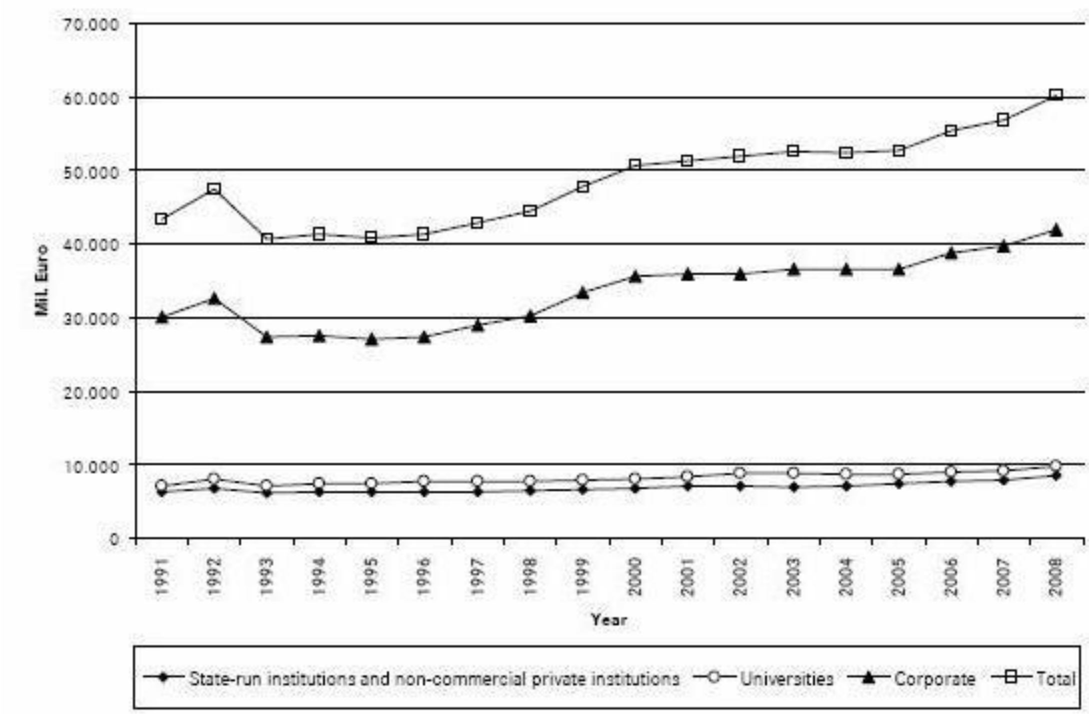
137 UNESCO Science Report 2010. UNESCO. 2010.

138 2012 Global R&D Funding Forecast. Battelle. 2011.

139 2012 Global R&D Funding Forecast. Battelle. 2011.

which accounts for nearly 70% of its R&D expenditure yearly.[140] In 2003, the industry accounted for $47.57 billion in R&D funding out of a total of $68.77 billion.[141]

Figure 4.26



Real-term figures, Federal Statistical Office, Fachserie 18, Reihe 1.5, Table 3.3; GDP index 2000=100 [142]

R&D investment in Germany by implementing sector, 1991-2008 (real-term figures) (1 euro = 1.29 USD)

Germany's universities and research institutes contributed $11.76 billion and $9.44 billion to this total, respectively, in the same year.[143] In 2007, Germany had spent 2.53% of their GDP on R&D, with 68.1% of this figure being made up by industry sources.[144]

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[140] Recommendations on German Science Policy in the European Research Area. German Center for Research and Innovation. 2010.

[141] Recommendations on German Science Policy in the European Research Area. German Center for Research and Innovation. 2010.

[142] Recommendations on German Science Policy in the European Research Area. German Center for Research and Innovation. 2010.

[143] Recommendations on German Science Policy in the European Research Area. German Center for Research and Innovation. 2010.

The R&D expenditure of the United Kingdom has remained stable over the last few years, increasing from 1.81% in 2010 to 1.84% in 2012.[145] On average, EU nations spend 13.3% of their R&D expenditure on defense. The UK is an exception, spending substantially more than the average, with 31% of its expenditure going towards defense projects.[146] Out of all of the performers of R&D in the UK, 61% of it is funded by the industry, while higher education contributes 27% to the nation's total expenditure. The government, together with various private non-profit organizations, makes up only 12% of the total R&D expenditure.[147]

Japan has been making efforts to increase their spending on R&D following the economic recession, which has affected them in the recent years. In 2010, the Japanese spent $148.3 billion on R&D (3.44% of Japan's GDP). This number increased to $157.6 billion in 2012 (3.48% of GDP).[148] Despite efforts to increase spending, the actual amount spent has not drastically changed over the last five years. Prior to the recession, however, Japanese R&D expenditure as a percentage of GDP climbed between 2002 and 2007, a time during which Japan was experiencing an economic upturn. During this same period, government expenditure on R&D decreased, pointing to the Japanese dependence on the private sector for funding. Japan's contribution to the global share of R&D spending has been on the decline recently, falling from 11.8% in 2010 to 11.2% in 2012.[149] Most of Japan's R&D spending originates from industry sources.

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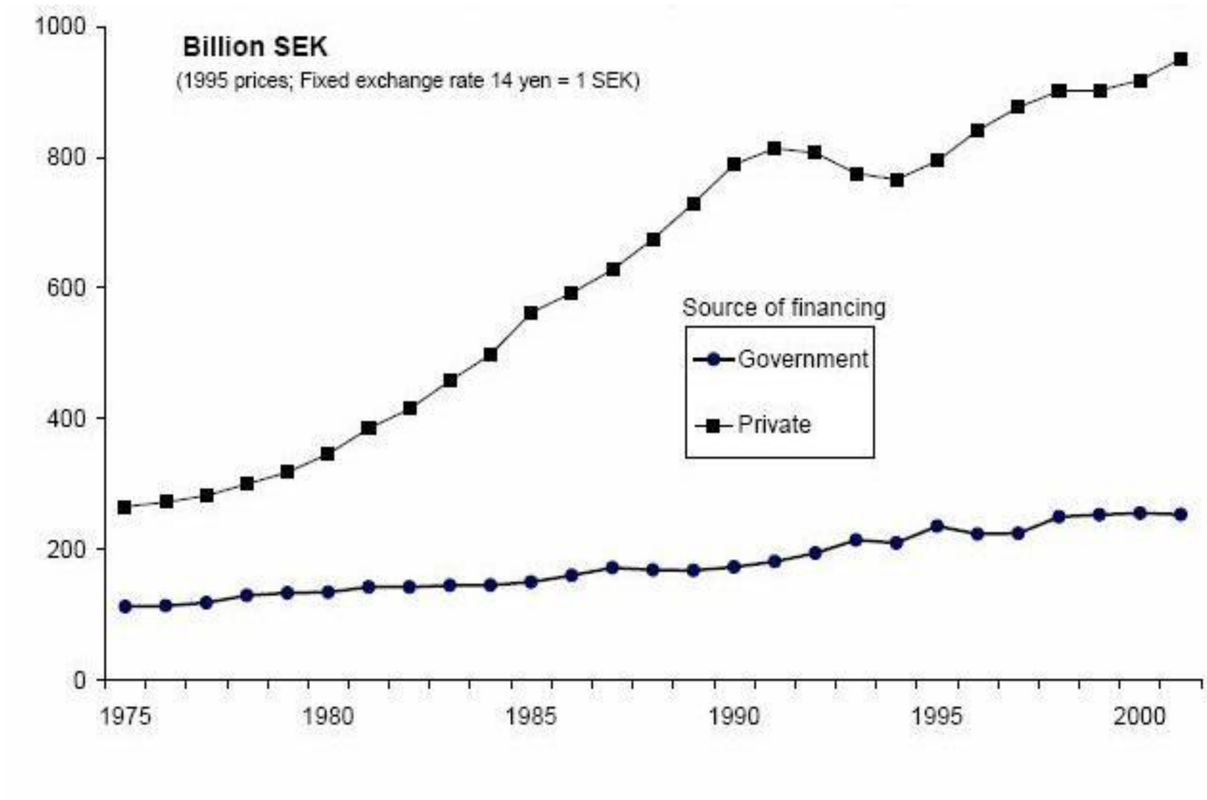
[144] UNESCO Science Report 2010. UNESCO. 2010.
[145] 2012 Global R&D Funding Forecast. Battelle. 2011.
[146] UNESCO Science Report 2010. UNESCO. 2010.
[147] "UK Gross Domestic Expenditure on Research and Development, 2010." Office for National Statistics. 14 March 2012. http://www.ons.gov.uk/ons/rel/rdit1/gross-domestic-expenditure-on-research-and-development/2010/stb-gerd-2010.html
[148] UNESCO Science Report 2010. UNESCO. 2010.
[149] 2012 Global R&D Funding Forecast. Battelle. 2011.

Figure 4.27



Source: White Paper on Science and Technology 2003. MEXT, June 2003. [150]

Development of R&D-expenditure in Japan 1975-2001 by source of financing (1 SEK = 0.15 USD)

In 2001, 73% of all of Japan's R&D expenditure was from the industry, with the government accounting for 19% of the expenditure.[151] Out of the government spending on R&D during this same year, 60% of it was provided to Japan's research institutes.

[150] Government Research and Innovation Policies in Japan. Lennart Stenberg. Swedish Institute for Growth Policy Studies. 2004.

[151] Government Research and Innovation Policies in Japan. Lennart Stenberg. Swedish Institute for Growth Policy Studies. 2004.

4.4.2 SCIENCE AND TECHNOLOGY POLICIES

For the most part, China's policy decisions are governed by five year plans which set forth economic goals for the Chinese people to pursue. These goals often reflect the increasingly scientific nature of China, though the policies set forth by China today were not always the policies of a well-oiled scientific machine. China's S&T policy has undergone a great number of reforms since the 1980s. Due to its predominantly socialist economy, the Chinese S&T network was plagued with many problems prior to and during the 1980s. Inherent with a socialist economy was an uncertainty regarding the availability of supplies. Many research institutes in China thus strived to be self-sufficient to counter this uncertainty, but this self-sufficiency had negative impacts on the research institutes, primarily through a severe lack of communication. As such, the duplication of results was a common issue in early Chinese scientific efforts. To further complicate problems, many of China's scientists, engineers, and technicians were inappropriately assigned to work units in which their expertise was of little value by the labor bureaus. For the most part, these assignments were permanent, with reassignment being a long and arduous process. One of the first efforts by China to remedy this situation was its 1985 "Decision on the Reform of the Science and Technology Management System". This decision brought a series of sweeping changes over the next several years regarding the way the nation as a whole administered its S&T system. One of the primary goals of this decision was to commercialize the technology that China developed by finding new ways to transform the technology into products and services. China's S&T administrative structure was also drastically overhauled. Whereas before research institutes had been directed under a central authority, institute directors were now given broader authority, including the freedom to seek out partners for cooperation on projects and the freedom to select research topics. In addition to the Decision, 14 Economic and Technological Development Zones were established in 1984 to promote the establishment of high-tech industries through financial incentives and the encouragement of FDI. The program has been so successful that today there are 49 of these zones.

China furthered its policy changes in 1996 with the "Decision on Accelerating Science and Technology Development", which set the tone for its future pursuit of science and technology. There were several goals outlined by the decision, the most important of which aimed to strengthen the S&T system by integrating it into the economy. The decision also called for the training of more STEM workers and sought to increase the proportion of economic growth attributable to scientific progress. With this decision, high-tech industries received financial support and were given high priority in the economy. These industries were encouraged to work closely with China's own research institutes and universities to produce new results. Under the decision, the government also created a special fund for certain projects while simultaneously creating new channels of funding to help other scientific ventures.

In 2006, China introduced its "Outline of the Medium- and Long-Term Plan for National Science and Technology Development (2006-2020)", which proposed that China become an innovation-driven nation by 2020. The pursuit of this ambitious goal is aided by government policies that are designed to encourage domestic innovation. The plan outlined five high-priority research areas and launched 16 megaprojects related to these areas. The megaprojects are designed so as to be affordable, bolster China's national security, cultivate strategic industries, focus on key technologies, and address the concerns of China's socio-economic development. As part of the outline, new mechanisms for the management of government R&D expenditure were developed in conjunction with preferential policies enabling enterprises to upgrade their R&D facilities. Additionally, tax incentives were offered to corporations for upgrading their facilities.

The vast majority of Chinese R&D is performed under three programs. The first of these, the National Program for High-Tech R&D (also known as the 863 Program), received $805.2 million in 2008 and focuses on specific scientific fields that are currently widely researched topics globally. The National Program for Key Technology R&D, which researches technologies that China believes will lead to continued commercial success, received funding of $729.5 million during the same year.[152] Finally, the National Program for Key Basic R&D (also called the 973 Program), responsible for the majority of China's basic research, received $273.6 million in funding in 2008.[153] Together, these three programs represent two-thirds ($2.02 billion) of all funding from the central government to national S&T programs, which had a total budget of $2.82 billion in 2008.[154] China also works to foster the relations between its research institutes and the industry, working on the idea that the commercialization of the results will increase profit as a whole.

[152] UNESCO Science Report 2010. UNESCO. 2010.
[153] UNESCO Science Report 2010. UNESCO. 2010.
[154] UNESCO Science Report 2010. UNESCO. 2010.

Much like China, India's policies are guided by broad five-year economic plans which set goals and targets for the economic development of the nation, many of which are tied to S&T policy. The short term goals set by the plans seek to address the nation's immediate needs while laying a foundation for the completion of long-term goals. The majority of these plans in the 1950s-1970s focused on industrialization. One of the earliest policies directly affecting S&T was the Scientific Policy Resolution, which was passed in 1958. This policy laid the groundwork for training STEM personnel on the scale needed to satisfy the demands of India's economic sectors at the time. Although the policies during these periods stimulated growth in India's economy, the rate of growth was not appreciable. In the 1980s, a series of economic reforms were initiated, some of which increased the growth of India's S&T sectors. Among these was the Technology Policy Statement (1983), which aimed to develop domestic technology and ensure the absorption of imported technology.

More recently, in 2003, a new Science and Technology Policy was announced, the objective of which was to raise R&D spending as a percentage of GDP from 0.8% in 2003 to 2% by the end of the Tenth Five-Year Plan in 2007. Although this target was not reached, the policy itself brought up some of the problems faced by India's S&T sectors today whereas previous policies had made little to no mention of these. Among the issues mentioned in the policy were the low density of scientists and engineers in the population, the large amount of brain drain, and the need for monitoring the implementation of policy. India's Eleventh Five-Year Plan contained provisions for a massive increase in the amount of spending for S&T by 220% over the Tenth Plan. Although this goal was not reached, the plan outlined several goals that India continues to strive towards, among them the enlargement of the pool of STEM workers, the establishment of globally competitive research facilities, and the identification of ways to catalyze industry-university collaboration. The National Innovation Act worked to develop an innovation support system and a national integrated science and technology plan.

A variety of policies have been implemented in India to help encourage the growth of its science and engineering sectors. One of the more effective measures has been the withdrawal of the tariff on capital goods, allowing the industry to bring in the equipment necessary to complete a variety of engineering projects at a significantly reduced cost. Additionally, whereas FDI had previously been discouraged, a new policy was introduced recently that allows 100% FDI. This policy has proven to be especially beneficial to India's engineering sector. Following in the footsteps of China, India also established a number of special economic zones throughout the country catering to enterprises engaged in science and engineering. Within these zones, a number of financial incentives, including the reduction of tariffs, provide a cheap base for high-tech industries and other international companies involved in R&D to set up offshore research facilities.

The formation of the European Union has made for interesting new S&T policies as its member nations collaborate more and more on scientific endeavors. Member nations, including the United Kingdom and Germany, work together to design and implement overarching policies in multiple areas while simultaneously supplementing these policies with their own at the national level. Oftentimes, conferences of the EU member nations will set goals for all of the members to strive for. One such goal was outlined in the Lisbon Strategy in 2000. This strategy sought to have each country strive to devote 3% of its GDP to R&D by 2010. The goal was not met, but many of the member nations continue to work towards this goal today.

Many initiatives in Germany have been created to expand the country's S&T sector. The Joint Initiative for Research and Innovation is an example of one of these programs. It provides funding to many of Germany's research facilities. The nation also developed the High-Tech Strategy, designed to remain in effect over the next 15 years. The Strategy has already seen a number of successes. Under it, industry investments in Germany increased by 19% between 2005 and 2008. The number of STEM personnel working in the industry also climbed 12% between 2004 and 2008, totaling 333,000 people.[155] Working on these successes and others, Germany has elected to continue developing this Strategy, which now encompasses policies that will finance innovation, standardize funding mechanisms for R&D, and increase the number of people available in its STEM workforce. The Strategy also established the High-Tech Start Up Fund. It provides $19.39 billion for the creation of high-tech programs. A number of EU programs also affect German R&D by providing additional benefits, which are mostly financial in nature.

The amount that the United Kingdom has spent on R&D has been falling since 1986. Even when the UK was faced with the effects of the recent economic recession, the recovery package that its politicians passed offered few incentives for science. Despite this, in the last six

[155] High-Tech Strategy 2020 for Germany. Federal Ministry of Education and Research. 2010.

years, there have been attempts to bolster the UK's S&T policy. In 2007, a number of recommendations from a review of the UK's science system were adopted, including extra funding for STEM education and $1.57 billion in funding for the Technology Strategy Board. Recently, in 2010, the UK's Science and Technology Facilities Council drafted a five year plan to improve the country's scientific capacity and keep British science competitive. The plan, called the Science Programme Prioritisation, includes greater funding resources for research in key fields, the development of two research campuses for collaboration between research institutes and industry, and continued support for the UK's current science and engineering outreach programs.

Japan sets the tone for its S&T progress through the Basic Law for Science and Technology. Enacted in 1995, this law marked a new beginning for Japanese S&T policy. Under it, many of Japan's national research institutes were given more freedom, including the freedom of drawing up their own employee contracts as they saw fit and the ability to keep leftover funding from previous years (which before had been nearly impossible due to bureaucratic limitations). Additionally, the law called for the creation of five year plans covering science policy, outlining short-term goals to achieve and setting long-term goals to work towards. The first Basic Plan, which ranged from 1995-2000, aimed to strengthen the cooperation between industry and the Japanese universities and research institutes. It also sought to increase the amount of resources and personnel available for R&D. The Second Plan, which spanned from 2001-2005, further developed the goals outlined in the First Plan. The Third Basic Plan, which was in effect from 2005-2010, worked to promote R&D in eight key fields. Between the Second and Third plans, some of the goals were shared, including the promotion of basic research and prioritized funding for the key research areas. The Council for Science and Technology Policy is responsible for drawing up the plans. With each plan, the budget for Japanese R&D expenditure has increased. The Second Plan called for a budget of $185 million, which increased to $193 million for the Third Plan. However, the nation fell short of these targets. Additionally, the Third Plan calls for the expansion of competitive R&D funds and active support for high-risk R&D.

The Creation of Innovation Centers for Advanced Interdisciplinary Research was launched in 2006 to build up Japan's R&D capacities through close cooperation between universities, the industry, and the government - a goal which had been outlined in the Third Plan. This was followed up in 2007 by the Global Centers of Excellence Program, which succeeded the earlier 21st Century Centers of Excellence Program. The Program provides 150 centers of excellence with support for five years. Japan has also rapidly increased the amount of competitive funds available to these and other facilities in the recent years. The funds, which are allocated on the basis of merit, increased from $3.67 billion in 2002 to $5.08 billion in 2007.[156] The various administrations in charge of S&T policy in Japan also established a variety of new funds to supplement Japan's competitive funding.

4.4.3 RESEARCH CAPACITY

A majority of federal government spending on R&D in the US goes towards funding the major performers of research in the US, which include the National Science Foundation (NSF), the National Aeronautics and Space Administration (NASA), and the Department of Defense (DOD). The NSF is a particularly special case, having been developed to support the efforts of science and engineering in universities and other non-profit organizations. As such, the NSF enjoys a certain degree of functional autonomy. In 2007, the federal government allotted $13.2 billion for 37 Federally Funded Research and Development Centers (FFRDCs)[157], which fill the role of national laboratories. As an indicator of the importance of universities in American research, the budget for university R&D in 2006 was $47.8 billion. Although universities accounted for only 14% of national R&D expenditure during this year, they performed 57% of the nation's basic research.[158] At present, there are 127 institutions in America that are classified as research universities. These universities receive over $15.5 million each year in federal funding, and all total about 200 US universities are responsible for almost all university research in America. For the most part, these universities receive their funding from the federal government, which provides nearly two-thirds of the funds. The industry makes up less than one-fifth of this funding. Recent budget cuts in American education have further put a strain on its research universities and universities in general by reducing funding across the board available for teaching new students and undertaking new research projects.

Research institutes are a major part of Chinese research. In 1985, China had already established almost 10,000 domestic research institutes, each of which was assigned tasks by various higher administrative bodies. Among these bodies is the Chinese Academy of Sciences,

[156] UNESCO Science Report 2010. UNESCO. 2010.
[157] 2012 Global R&D Funding Forecast. Battelle. 2011.
[158] UNESCO Science Report 2010. UNESCO. 2010.

which is considered the most prestigious scientific organization in China. The Academy oversees 3,700 institutes, 1,350 universities, and multiple industrial enterprises which operate nearly 30,000 corporate R&D labs. The number of foreign corporate R&D labs has been increasing during the recent decades, providing a strong indicator of China's attractiveness to businesses as a region for the establishment of R&D centers. There were fewer than 50 corporate research centers in 1997, but by 2004 this number had increased to over 600.[159]

Offshore R&D centers are by far one of the largest sectors of India's science and engineering economy. Fewer than 100 foreign R&D centers had been established in 2003, but this number had grown to 750 by the end of 2009.[160] Even in 2003, there were nearly 23,000 scientists employed at these foreign R&D centers. The total value of these centers in 2003, including the value of the personnel they employed, was estimated to be $2.3 billion. In a random sample of 100 of these facilities, 53 were owned and operated by American-based corporations.[161]

Much of Germany's research is performed by its research institutes, which often receive 100% of their funding from the federal government and the states in which they are located. Some of these institutes are well known around the world, including the Max Planck Society and the Fraunhofer-Gesellschaft.[162] Altogether, Germany operates 55 national and 188 regional research institutes dealing with a wide variety of scientific and engineering fields. Germany often works to bolster its institutes and research universities through policies that provide extra funding. As part of Germany's Excellence Initiative, 37 'clusters of excellence', research groups involved in several disciplines and encompassed by several institutions within a region, were selected to receive extra funding. In Germany, all research institutes are regularly evaluated by the German Science Council. The research institutes take the findings of the Council's evaluations very seriously and work to implement solutions to problems identified by the Council. Despite a strong system existing for the evaluation of institutional research, there is still no system for evaluating university research in Germany.

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159 UNESCO Science Report 2010. UNESCO. 2010.
160 UNESCO Science Report 2010. UNESCO. 2010.
161 Science, Technology and Innovation Policy in India under Economic Reform: A Survey. T. Jayaraman. 2009.
162 "Germany's science and research landscape". Federal Government of Germany. 2006. http://wm2006.deutschland.de/EN/Content/Host-Country-Germany/Germany-in-brief/germanys-science-and-research-landscape.html

Much of the United Kingdom's research is carried out by the Royal Society, the British Academy, and the Royal Academy of Engineering. There are two types of funding available for research in the country. In 2010, roughly $4.39 billion of university research funding came from research councils, while a further $2.35 billion came from institutional funding.[163] This institutional funding is generally given out through the Research Assessment Exercises, which decide how to allocate funding among these universities. The scheme itself is highly competitive, featuring strong incentives for winners and penalties for losers. The system itself has no analog in any other nation in the world and continues to be a debated policy in the UK.

In 2007, there were 4,663 researchers per million population in the United States.[164] There were significantly less in China during the same year, at 1,071 researchers per million population. The number of scientists and engineers in China more than doubled between 2000 and 2008 to 1.59 million and continues to increase, indicating that China is closing the gap with America.[165] India has a very low proportion of researchers to population, with only 137 researchers per million population.[166] This low density of researchers is punctuated with shortages of technically trained personnel within the nation. In a survey conducted in 25 industrial sectors, there was a 25% shortage of skilled personnel in the engineering sector. Emigration by highly skilled Indians as a share of those in tertiary education increased from 2.6% in the 1990s to 4.2% in the early 2000s.[167] To further complicate India's brain drain problems, foreign R&D centers often offer better incentives, luring India's already small pool of scientific talent to these centers. Germany and the UK have a comparable density of researchers to population, at 3,532 and 4,181 researchers per million population, respectively.[168] Japan by far has the highest density of all of the countries considered, with 5,573 researchers per million population[169]. Between 2003 and 2008, the number of researchers in Japan had increased by 9.2%. Most of the increase was attributable to the industry sector.[170]

[163] UNESCO Science Report 2010. UNESCO. 2010
[164] UNESCO Science Report 2010. UNESCO. 2010
[165] UNESCO Science Report 2010. UNESCO. 2010
[166] UNESCO Science Report 2010. UNESCO. 2010
[167] UNESCO Science Report 2010. UNESCO. 2010
[168] UNESCO Science Report 2010. UNESCO. 2010
[169] UNESCO Science Report 2010. UNESCO. 2010
[170] UNESCO Science Report 2010. UNESCO. 2010

4.4.4 SCIENTIFIC OUTPUT

American scientists contribute significantly to the scientific output of the world as a whole. In 2006, approximately 44% of all S&T articles published in journals globally, as listed by Thomson Reuters, involved at least one US author. Out of these authors, 74% were involved in academia. By 2008, the total number of papers published by American scientists had reached 316,000.[171] Between the four year periods of 1993-1997 and 1997-2001, the contribution of the United States to the total amount of scientific literature globally fell from 52.3% to 49.4%, giving clear signs that the rest of the world is catching up with America.[172]

China is an example of one nation catching up with the US. Between 2000 and 2007, the number of Chinese research papers nearly tripled from 30,499 to 89,147, increasing at an average yearly rate of 17.3%.[173] As a testament to the increase in quality of Chinese science, the number of papers that were highly cited in other scientific literature more than doubled between the four year periods of 1993 to 1997 and 1997 to 2001. However, this increase in quality, when viewed relative to the quality of science from other nations, is not yet up to par with the world leaders of science: the average citation rate for Chinese papers during 1999 to 2008 was only 4.61, a relatively low number, showing that a gap in quality still needs to be addressed. More recently, in 2011, China became second only to the United States in the global share of papers written in English. From 1993 to 2003, China had contributed only 4.4% to the total number of such papers. Between 2004 and 2008, however, that proportion had grown to 10.2%.[174]

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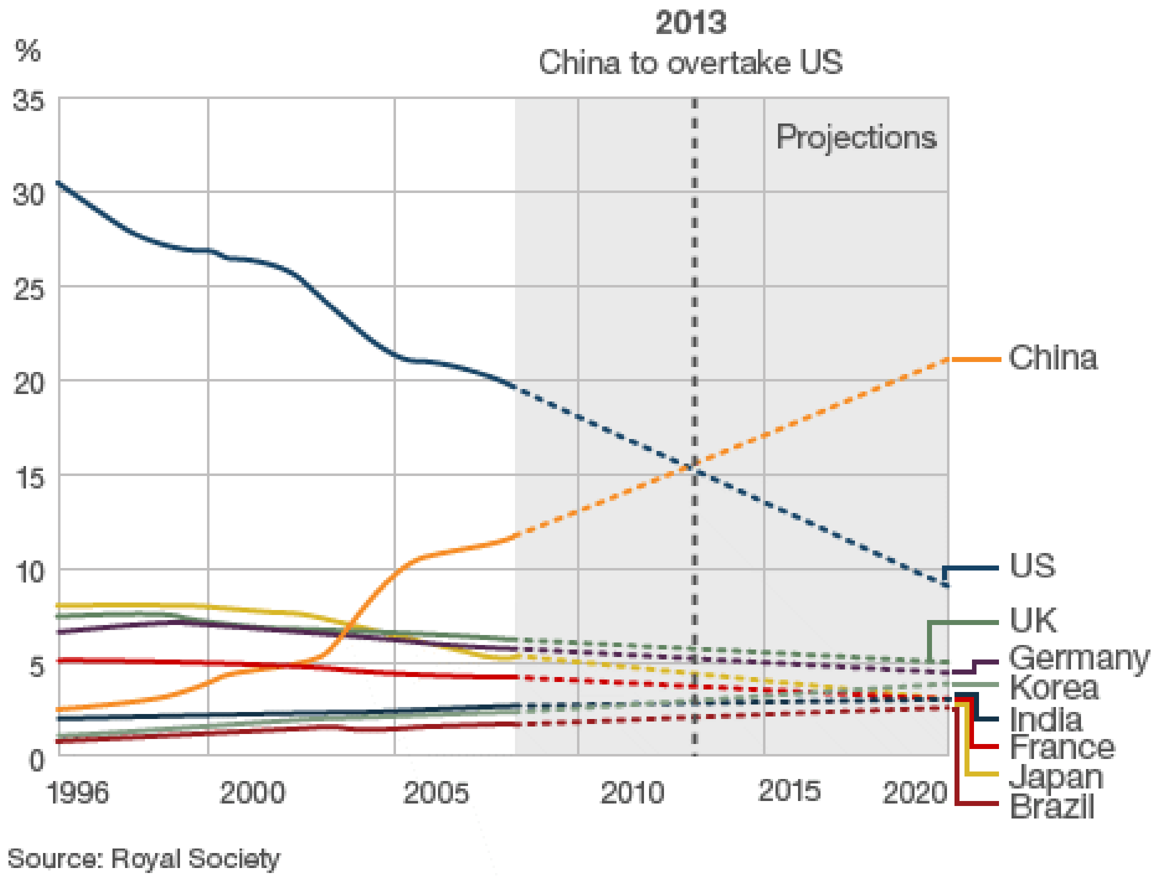
[171] UNESCO Science Report 2010. UNESCO. 2010

[172] "China, Brazil and India lead southern science output." David Dickson. SciDev.Net. July 16, 2004. http://www.scidev.net/en/news/china-brazil-and-india-lead-southern-science-outp.html

[173] UNESCO Science Report 2010. UNESCO. 2010

[174] UNESCO Science Report 2010. UNESCO. 2010

Figure 4.28



[175]

Projected growth in citations in scientific literature

The graph above depicts the percentage of highly cited scientific papers globally. Although America holds a significant majority of the share of these papers, China is quickly catching up to us. Even by a linear projection, China is poised to overtake the United States as the leading producer of quality research, perhaps as early as 2013.

India is yet another nation that is catching up in terms of scientific output, though at a far slower pace. Globally, India contributed 1.68% of the world's scientific literature in 1993. In 2003, this figure had barely increased to 1.77%.[176] Despite the slow increase, Indian scientific publication has been on the rise since 2003. At its present rate, India could overtake the G8

[175] Shukman, David. "China 'to overtake US on science' in two years". BBC News. March 28, 2011. http://www.bbc.co.uk/news/science-environment-12885271

[176] UNESCO Science Report 2010. UNESCO. 2010

nations between 2015 and 2020. In particular, Indian scientists and engineers had published 12,000 papers in 2000, most of which originated from university research.[177]

The EU itself is responsible for a great deal of research globally. Its global share of all scientific literature is currently at 37.6%.[178] Germany is one of the EU nations which accounts for a bulk of the scientific work done in the EU, contributing roughly 28% of all research in the Union. On the whole, the total number of papers published by German scientists has been increasing by 4.5% from 2000 to 2008.[179] During the same period, their share in the number of the top 10% of the most cited papers increased at a rate of 5.9%.[180] In 2008, Germany had published a total of 76,368 papers. In addition to this, the United Kingdom had published an additional 71,302 papers.[181] The UK's share of scientific literature globally declined from 6.7% in 2006 to 6.4% in 2010. Despite the decline, the number of highly cited papers from the UK has been on the rise, growing at a rate of 7.2% annually since 2006, which is higher than the world average of 6.3%.[182]

Japan's share of publications has dropped recently. Although it produced 10% of the world's papers in 2002, this figure had fallen to 7.6% by 2007. This number has continued to fall, reaching 6.6% in 2010. Japan's share of the top 10% of scientific publications also declined from 8.2% in 2002 to 7.5% in 2007. Papers coauthored with non-Japanese scientists represented 23.9% of all Japanese scientific papers in 2007.[183]

4.4.5 STEM EDUCATION

Enrollment in colleges in the United States has been increasing rapidly in the recent years and, along with it, the number of STEM degrees being produced. The number of STEM degrees received in America reached about half a million in 2009 and, with the exception of computer sciences, the number of these degrees are projected to continue growing. Additionally, the number of graduate degrees earned in STEM fields has been on the rise. The number of Master's

[177] UNESCO Science Report 2010. UNESCO. 2010
[178] Innovation Union Competitiveness Report 2011. European Commission. 2011
[179] Innovation Union Competitiveness Report 2011. European Commission. 2011
[180] Innovation Union Competitiveness Report 2011. European Commission. 2011
[181] UNESCO Science Report 2010. UNESCO. 2010
[182] International Comparative Performance of the UK Research Base - 2011. Elsevier. 2011.
[183] Japanese Science and Technology Indicators 2010. National Institute of Science and Technology Policy. 2011.

degrees jumped from 120,000 in 2007 to 134,000 in 2009, and in 2009 alone, roughly 41,000 STEM doctorates were awarded.[184]

Since the 1990s, China has been working to reform its university system. The most significant of these reforms has been a large increase in funding. University funding reached $10.4 billion in 2003, more than doubling the amount of funding since the reforms began. In addition, China has targeted several key universities for extra funding in order to make them "world class", much like the Ivy League schools of the United States. Another policy that China has adopted is the use of exchange programs. These ensure that there are few mismatches between curricula and the skills that are necessary for graduates to be successful in their field. Every year China produces roughly 442,000 undergraduates in engineering fields.[185] To add to these numbers, there are 48,000 masters degrees and 8,000 doctoral degrees awarded in engineering fields each year. There were roughly 1.5 million students that graduated from Chinese universities majoring in science and engineering during 2006.[186] Roughly 21,000 of these graduates were earning doctoral degrees.[187] China actively seeks to increase its STEM talent and even approaches Chinese professors working in America. By offering these professors better benefits, these professors go back to China to teach and improve China's education system by using their knowledge of the American education system and implementing it into China's.

The number of undergraduates attending school in India for the sciences and engineering has been on the rise with an annual growth rate of 12%.[188] A vast majority of the majors pursued in the Indian universities are in the science and engineering fields. In 1995, 70.5% of graduates from universities were majors in science, with an additional 15.4% of graduates being concentrated in fields of engineering and technology.[189]

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[184] Science and Engineering Indicators 2012. National Science Board. 2012. http://www.nsf.gov/statistics/seind12/

[185] "China Luring Scholars to Make Universities Great". Howard French. New York Times. October 28, 2005. http://www.nytimes.com/2005/10/28/international/asia/28universities.html?pagewanted=1

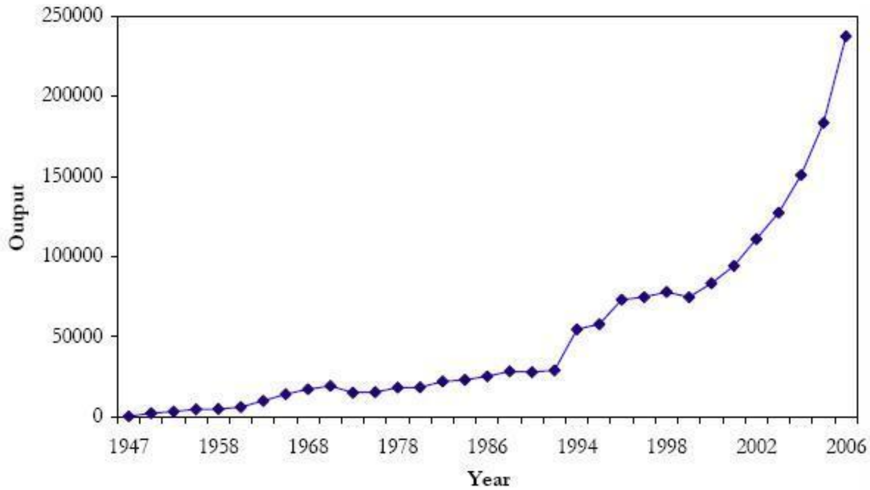
[186] "World Bank says China could overtake US by 2030". Taipei Times. March 24, 2011. http://www.taipeitimes.com/News/biz/archives/2011/03/24/2003498946

[187] "China Luring Scholars to Make Universities Great". Howard French. New York Times. October 28, 2005. http://www.nytimes.com/2005/10/28/international/asia/28universities.html?pagewanted=1

[188] UNESCO Science Report 2010. UNESCO. 2010

[189] Science, Technology and Innovation Policy in India under Economic Reform: A Survey. T. Jayaraman. 2009.

Figure 4.29



[190]

Total output of engineering graduates at Indian universities, 1947-2006

In 2006, there were roughly 237,000 students in attendance for engineering disciplines alone.[191] Presently, one-quarter of India's student body is enrolled in STEM fields. Part of this is due to efforts that the nation has taken to introduce science and engineering to young children early in their education. This generates interests in the young students and opens their eyes to the possibilities offered by STEM majors. Additionally, India has proposed a plan to fund 500 of its top students. The funding provided would be guaranteed for 15 years, starting at the age of 17, allowing these top students to pursue careers in the sciences. There has been a significant increase recently in the number of master's degrees awarded. There were 14,000 of these degrees awarded in 2001, leaping up to 20,000 in 2006. The number of PhDs awarded, however, is lacking. As of 2003, India is producing only 4,500 doctorates every year.[192]

The quality of India's higher education system is often called into question. The education system has only evolved in the last 60 years. In 1950, there were only 50 institutions which granted degrees. This number has since expanded to 1,668 in 2007.[193] Funding for higher

[190] Science, Technology and Innovation Policy in India under Economic Reform: A Survey. T. Jayaraman. 2009.
[191] Science, Technology and Innovation Policy in India under Economic Reform: A Survey. T. Jayaraman. 2009.
[192] Science, Technology and Innovation Policy in India under Economic Reform: A Survey. T. Jayaraman. 2009.
[193] India - Country Summary of Higher Education. World Bank. 2007.

education was also similarly paltry in the beginning; only $3.13 million had been set aside for the funding of higher education as a whole. Today, the amount of funding available is $1.7 billion[194]. Despite the rise in the number of institutions and the amount of funding, there are many problems that have yet to be addressed. The enrollment rate of Indian schools is low - nearly 10%, compared to a global average of 23.2%.[195] Compared to the global average of 23.2%, the number of Indian students enrolled in universities is about half of that figure. The quality of education also varies widely from university to university. One study in particular stated "not more than 15% of graduates of general education and 25-30% of technical education are fit for employment."[196] The core of the problem lies in the fact that many universities go unregulated due to their ineligibility for funding by the University Grants Commission. Due to this, they are not monitored by the National Assessment and Accreditation Council, the governmental body responsible for quality control of Indian universities. In fact, 90% of colleges and 68% of universities in India are rated to be of poor quality by the NAAC. Even more startling is the fact that 57% of the faculty in these poor colleges do not have post-graduate credentials.[197]

One of the more successful stories of Indian education is that of the Indian Institutes of Technology. These schools have an excellent reputation internationally as centers of higher learning, especially in the STEM fields. Their establishment led to the growth of higher education in science and technology fields during the 1980s. Although there were originally eight of these, the government has recently begun to increase the number of these institutes to sixteen. Another measure taken to address these problems that has made a positive impact is the allowance of certain universities to open campuses in other states. The government itself is also establishing new central universities which it owns and operates, allowing quality assurance to be built directly into the new colleges. In 2010, the government was considering a policy that would permit foreign universities to enter the higher education system through the establishment of their own campuses or joint ventures with existing universities and institutes. A wide variety of initiatives have been proposed or enacted to help fix the problems with the Indian higher education system, all of which experience varying degrees of success.

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[194] India - Country Summary of Higher Education. World Bank. 2007.
[195] India - Country Summary of Higher Education. World Bank. 2007.
[196] India - Country Summary of Higher Education. World Bank. 2007.
[197] India - Country Summary of Higher Education. World Bank. 2007.

The EU produces more PhD degrees on average than the US. In a study conducted of 19 EU members, 1.4% of citizens during the study earned a PhD, compared to 1.3% of people in the US, 0.8% in Japan, and 0.1% in China.[198] Lately, the EU has been attempting to unify the education system of its various members in what is known as the Bologna Process. The Bologna Process is a vast series of reforms designed to remedy differences in quality and curricula between the different nations. Some of the reforms that have been introduced by the Process include changes in funding for universities and alterations of the ways in which universities collaborate with the industry. A number of other concerns, such as increasing diversity, are addressed through the Bologna Process.

The university system in Germany is quite different from the American school system. There are, at present, 350 universities in Germany, most of which are publically funded. Two types of universities offer degrees in engineering. The first of these are the technical universities, which place an emphasis on theory. These programs typically involve five to six years of coursework. Most students attending these schools go on to get jobs in education or R&D. The other type of school are the *Fachhochschulen,* which places more emphasis on application. These schools work closely with the industry. A senior's year in these schools is spent working in an internship with a company, gaining valuable hands-on experience and possibly securing a job when they graduate in the same company. Because the industry works closely with universities, much thesis work that is completed relates to actual commercial R&D and the development of new technology. In 2005, about 100,000 individuals worldwide completed a doctorate - almost double the US figure of 53,000.[199] Of these, more than 24,000 graduated in Germany.[200] Germany and the UK together are responsible for producing 40% of all new doctorate holders in the EU[201].

Germany has taken several initiatives to expand its STEM education sector. In principle, this is difficult because education is a responsibility of the states, and as such the federal government needs to work carefully when it introduces new policies related to higher education.

[198] UNESCO Science Report 2010. UNESCO. 2010.

[199] Recommendations on German Science Policy in the European Research Area. German Center for Research and Innovation. 2010.

[200] Recommendations on German Science Policy in the European Research Area. German Center for Research and Innovation. 2010.

[201] Recommendations on German Science Policy in the European Research Area. German Center for Research and Innovation. 2010.

One of these is the Excellence Initiative, started in 2005, which seeks to lift a select few universities up to "elite" status in addition to promoting the efforts of up-and-coming scientists. It does so by inviting universities to submit strategic plans of its future research to compete for a total additional funding of $2.71 billion. Another part of the Initiative selected 39 excellent graduate schools over time to receive extra funding. One of the more prestigious portions of the Initiative has universities submit strategic plans for their institution as a whole. So far, only 9 universities have received funding from this part of the Initiative. The Higher Education Pact is an example of policy that impacts Germany's higher education in a broader sense. It provides extra funding for Germany's universities, allowing the schools to take in more students. In 2009, the pact led to 423,000 new students being accepted into the German school system.[202]

Although college attendance has grown in the UK, the number of students receiving degrees in engineering fields has increased only by 3% in the last decade. The UK produces roughly 90,000 graduates in STEM fields per year, but there are concerns that this number will not be enough for the future needs of British science. A study by the Royal Academy of Engineering claims that the UK will need 100,000 STEM graduates per year to keep up with other nations.[203]

There are a number of programs in place to improve the state of the UK's STEM education system. One of these programs is the Best Programme, which seeks to recruit students into STEM fields and generate collaboration between universities and industry, providing the new students with extra training and education through these collaborations. To further generate interest among younger students, the CASCADES Project sets up after-school clubs and helps teachers with Continual Professional Development in a number of primary schools. The Engineering Further Education helps colleges build better engineering curricula that are both engaging and attractive to students. One of the more interesting projects is undertaken with the help of BAE Systems. Called the Engineering Engagement Project, this project supports STEM education through a national network with the aim of widening participation in STEM fields.

Japan's university system is different from that of America's as well. There are three classifications of universities: private, national, and public. Although private universities have

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[202] Strengthening Germany's role in the global knowledge society. Federal Ministry of Education and Research of Germany. 2008.

[203] "Warning over shortage of engineering graduates." Hannah Richardson. BBC News. 30 September 2012. http://www.bbc.co.uk/news/education-19760351

the largest share of undergraduate education, with 78% of all bachelor's degrees awarded from these institutions, most graduate work comes from the national universities. About 72% of all completed doctoral degrees come from Japan's national universities. In 2002, Japan produced a total of 123,000 undergraduates in the fields of science and engineering, approximately 22% of the total number of students who completed coursework that year. During the same year, 34,729 master's degrees and 4,680 doctorate degrees were awarded in the same fields. In fact, 40% of the doctorate degrees come from eight universities, all but one of which are national universities.[204] Enrollment in higher education, however, has begun to drop off recently, despite having climbed steadily until 2002. Since 2003, enrollment at the undergraduate level has stagnated and, at the graduate level, has started to decline rapidly. To counter this, Japan has adopted various initiatives for graduate students to allow these students to acquire a broad range of skills through internships with the hope that this will allow for a smooth transition to the private sector.

Japan's universities are currently under pressure to change their mode of operation. In 2004, all of Japan's national universities were semi-privatized and relabeled as "national university corporations". The schools adopted new methods of accounting that are akin to the methods of a business as well as changing their internal governance by the introduction of boards of directors. Some of the members on these boards are even deliberately selected due to their lack of affiliation with the university itself. Japan also instated a system of external evaluation for its universities to help ensure quality. A number of regulations have also been abolished, increasing the financial autonomy and flexibility of Japan's national universities. This helped to encourage university-industry collaboration in R&D. Recently, reduced funding and government subsidies for Japan's private universities has dealt a blow to Japan's university system.

4.4.6 CONCLUSIONS

It goes without saying that, without proper funding, America's science programs will fall behind the programs of other nations. China's meteoric rise onto the stage of global S&T is accompanied by an ever-increasing expenditure on R&D, having grown from 0.6% to 1.6% between 1995 and 2011. This increase was paired with an increase in the investment of industry

[204] Government Research and Innovation Policies in Japan. Lennart Stenberg. Swedish Institute for Growth Policy Studies. 2004.

in Chinese R&D, having grown from 60% to 73% between 2000 and 2008. Similarly, although India's efforts to increase its R&D spending have been slow at best, the country is nevertheless growing economically at a highly rapid pace. India's expenditure on R&D increased from 0.8% to 0.9% between 2003 and 2007, but more striking is the increase of industry funding of R&D during the same period: 18% to 28%. Even in more developed nations, R&D spending tends to be an appreciable share of total GDP. Japan spent an astounding 3.48% of its GDP on R&D in 2012, with industry contributing nearly 70% to the total amount of R&D expenditure. Germany spent 2.87% of its GDP on R&D in 2012, one of the highest in the EU; it aims to increase this amount to 3% in the coming years. In contrast, the United Kingdom spent only 1.84% of its GDP on R&D in 2012. Presently, America spends 2.7% of its GDP on R&D. Under the Obama Administration, America has set a goal to increase its R&D spending to 3% of GDP. This is a step in the right direction, though not all funding must be provided solely from the government. It is evident that industry plays a significant role in achieving this high level of expenditure. In nations like Japan, Germany, and China, where industry contributes 60% or more of R&D expenditure, the total R&D expenditure as a percent of GDP is correspondingly higher. It will be beneficial for America to foster relations between its own research institutes and the industry in addition to increasing its R&D funding.

Additionally, many nations generate plans to guide their policy decisions over a short time span, typically five years. Japan is one such nation, with its Basic Science and Technology Plans, which set a variety of S&T goals. The goals range from increases in funding to the identification of key research areas. Even in nations like India and China, where there are five year plans of a broader economic context, goals that are outlined often have relevance to S&T. Goals that are set forth can include increasing the current pool of STEM talent and the creation of policies that offer incentives to industry. In practice, determining the efficiency of such plans is not possible, since the plans themselves are merely sets of goals. However, in all of the countries considered where five year plans are implemented, the policies created during the time frame of these plans tends to follow the general suggestions outlined. An example of this includes India's Technology Policy Statement of 1983, which came on the heels of economic reforms in 1980s India that shifted the nation's focus from industrialization to S&T. By defining a direction for future American research, the United States could benefit. Not only will the establishment of short term goals give focus to Congress, but also they will allow us to lay the foundations for long-term S&T goals, as other nations have done. Only by having a clear direction will our nation be able to stay competitive with other nations in science and engineering. Our nation cannot continue to be blindly steered through foggy waters.

Of course, all of the funding and planning will be for nothing if America does not have a sizable pool of STEM talent from which it can draw. Each year, China produces almost 442,000 engineering graduates, ready to enter the workforce. Similarly, in 2006, India had generated 237,000 engineering students. Although India itself is facing a shortage of STEM workers and still has a higher education system marred by quality issues, it is clear that these two developing nations are contributing a significant amount to their own pools of S&T talent. Both nations strive to introduce science and engineering to students early through the use of outreach programs and the incorporation of science and engineering knowledge into its K12 curricula. America can follow in this example by the establishment of its own programs in order to generate a wider interest in the STEM fields among younger students. However, there are factors driving the impressive STEM output of these developed nations that, no matter what, America cannot change for itself. Among these is the culture of China: in a government that frowned upon free thought throughout the decades following the Cultural Revolution, the pursuit of education in the humanities fell significantly. Even to this day, many Chinese students still seek STEM degrees from Chinese universities rather than pursuing the liberal arts. In Germany, one of the two EU nations responsible for producing 40% of all doctorate holders in the Union, internships are a routine part of higher STEM education. These are especially advantageous in that students receive hands-on experience and often times have jobs waiting for them upon graduation. It is worthwhile for America to consider adopting a similar policy. With real-world experience directly involved in its education, American STEM graduates will retain the high standards of quality that they have been known for already. In addition to this, by encouraging internships as part of education, universities and industry will begin to work closer, helping America to work towards the previously suggested goal of increasing its R&D expenditure. As a final note, America should find ways to make it easier for students educated in STEM to work and live in the country. Nearly two-thirds of America's foreign STEM graduates are from India and China and the overall share of foreign students earning STEM degrees in America is one-third.[205] The possibility of extending work visas to students who come to America to be educated or a

[205] Science and Engineering Indicators 2012. National Science Board. 2012. http://www.nsf.gov/statistics/seind12/

smoother immigration process for those who have already been educated with a STEM degree should be considered. Not only will this add to America's STEM talent, but it will also help to foster diversity in the STEM fields, an issue which America still has yet to completely address.

5.0 RESULTS AND CONCLUSIONS

The intent of this section is to conclude the findings of the group project. The initial goals for the project were to:

- To make suggestions to United States policy makers toward ensuring the continued leading status of the U.S. in engineering and technological fields, with specific attention to education and economic policy.
- To make predictions and draw attention to solutions for the future direction of engineering education on a national scale.
- To suggest to Worcester Polytechnic Institute ways to attract and retain students to engineering majors which are importation yet have low enrollment trends.

In the following subsections, the group will make recommendations pertinent to Worcester Polytechnic Institute and then the nation as a whole.

5.1 UNIVERSITY

At the university level, based on the group's research, several things that universities would benefit from would be: (1) increased partnership with businesses and the local and federal government; (2) increased diversity in student populations; (3) up-to-date engineering curricula; (4) more thorough admissions processes for prospective students and; (5) guidance for students regarding the selection of their prospective majors. These conclusions are explained and justified below in more detail.

Creating a cluster of partnerships among universities, businesses, and government creates a unified direction towards growing a specific region. The university creates qualified workers and the government works with local businesses to let them invest in the area. Then the businesses hire the qualified students. Partnerships between businesses and universities provide opportunities for students in STEM majors to receive hands-on training through internships as well as the chance to have a job upon graduation.

As outlined in the education conclusions section, diversity is a big factor in STEM education, as it provides a broader perspective from which students can examine their projects. Students from foreign nations bring with them different customs, cultures, and viewpoints, which generates a larger pool of ideas that can be worked with, as well as increased understanding of different cultures and how differing ideals can affect engineering projects as a whole.

Having up-to-date curricula is important because it enables students to adapt their skills to new and emerging technologies as well as providing insight regarding current topics within their fields of study. While studying the past is important in order to give students an idea of the failures of previous scientific endeavors, the future should be the primary focus of programs of study, for it is the future that today's students will work in.

As it stands, there is noticeable variation in the rigor behind admissions processes for different universities around the world. The research data shows that universities with more rigorous admissions processes rank higher, both overall and in STEM fields. By improving their standards of admission, universities will educate only the best and brightest students available, creating highly qualified workers that will go on to pave the way of the future. While this may seem to cut the applicant pool, it can be used to select the same amount of better qualified students based on more comprehensive metrics.

Universities should provide resources for undergraduates in their first and second years of study to better guide them in their quest to select a major. Universities can provide classes which provide underclassmen with exposure to broad topics in the fields of engineering. Worcester Polytechnic Institute offers one such class for its civil engineering majors, titled 'Civil Engineering and Computer Fundamentals', which surveys the scope of civil engineering and its subfields. Classes aimed at non-majors are also available, such as WPI's 'Systems Programming for Non-Majors', which allows for background information in computer science with adequate depth for a non-CS major.

With the increased support from local businesses and government bodies, universities could continue to update their engineering curricula to support the needs of the engineer of the future. This can be seen in how Project Lead the Way is set up with a "curricula of hands-on, problem-based, technology-driven learning"[206]. With an enriched curriculum, there can be more room for classes that are geared towards the selection of specific majors; classes like CE1030 are CS110X are currently being offered at WPI and are examples of such classes. Classes like these help guide students to their respective degree programs. Just as introductory classes provide a broad overview of a topic, a diverse student body would do the same. As Duderstadt says, "students constantly learn from each other in the classroom and in extracurricular life. The more diverse the student cohort, the more opportunities for exposure to different ideas, perspectives and experiences and the more chances to interact, develop interpersonal skills, and form bonds that transcend difference."[207] Therefore, a diverse student body at WPI would be desirable for the different ideas and perspectives that students would be exposed to both in the classroom and in their social lives. All of these are based on the students that are enrolled at a university. Therefore, a comprehensive admissions process is necessary to select the best students for the university. To reiterate, MIT admissions office ensures that "at least a dozen people will significantly discuss and debate an application before it is placed in the admit pile." [208] Although this costs more money and manpower, the most qualified candidates will be reviewed thoroughly.

5.2 NATIONALLY

At the national level, the group sees room for improvement regarding the way the American government handles STEM education. The group would suggest that the government should: (1) create more STEM education programs at the K-12 level; (2) make obtaining a visa easier for foreign students applying to universities and for those who have already obtained a STEM degree, and; (3) increase funding for universities and federally-funded research projects.

Following up on the success of Project Lead the Way, more programs of similar nature aimed at the K-12 level can be used in an effort to increase STEM education at younger ages. They can also be directed towards girls and minority groups to attract them to engineering majors. This would hopefully increase both diversity in engineering programs and increase the

[206] "The Engineer of 2020: Visions of Engineering in the New Century" Ch. 4
[207] "A University for the Twenty-first Century" Ch. 9
[208] http://mitadmissions.org/apply/process/selection

total amount of people interested in pursuing STEM. These programs will also give potential students a head start in their field, giving them an idea of what to expect in their chosen major.

The mindset of an engineering student is highly desired in corporations, both in America and globally. However, foreign students that are educated in America are sometimes required to leave upon the completion of their degree program, thus allowing for the abuse of the American education system. In a speech made to Stanford University, Craig Barrett, the former CEO of Intel, suggested that STEM degrees should come with a green card “stapled” to it. The group agrees with this idea.

National universities would benefit greatly from government investments in research. There are some university research labs in the US that are highly successful, such as Oak Ridge, which is backed by the Department of Energy and Lincoln Labs, which is backed by the Department of Defense. These labs have produced technology used by the military and the general public. Extra funding would allow these and other labs, as well as universities, to continue contributing to the technological achievements of America. For instance, ARPANET, which became the backbone of the Internet, was developed in part by Lincoln Labs. More research would allow America to continue to sow the seeds of innovation.

To keep engineering competitive at a national level, the US should consider creating more STEM education programs at the K-12 level. There has been growing interest in programs such as Project Lead the Way, which are geared towards middle school and high school students. Programs like these engage students in science, technology, math, and engineering at an early age. Programs like Project Lead the Way are supported by local colleges and universities, such as the case of the Science and Technology Magnate High School of Southeastern Connecticut, which is supported in part by the University of New Haven and Mitchell College. By having these programs, it can introduce younger students to universities conducting research that pertains to their interests. To keep this inspiration alive, funding for universities like WPI and other research institutions needs to not only continue, but also increase. Inspiration not only lies with future American engineers, but also with foreign students who wish to come here to study. Making student visas more readily available to those wishing to study in the STEM fields would allow more motivated foreign students to join the ranks of America’s universities and add to the diversity of the student populations. To this end, the nation should make it easier for those graduates who wish to stay and help in engineering fields, because keeping these newly educated foreign graduates in the United States to work would help diversify the workplace and would serve as a way of increasing America’s STEM talent pool.

Although it is evident that America’s position is losing ground to other nations, the problem is remediable. Suggestions can be made at the university level and national level in the fields of education, employment, politics, and technology that will provide a beacon of light shining through the fog of an uncertain future. For this country to succeed, America must commit to changing its direction in order to sustain our global competitiveness.

The statistics regarding the position of other nations regarding engineering and technology are alarming in comparison to that of the United States. This is not without good reason. There is no doubt that other nations, such as China and India, are rapidly catching up to the US while our own nation is beginning to lag. Although this is not an irreversible situation, action must be taken soon or we risk slipping down and losing our leadership in STEM fields across the world. It is highly unlikely that there will ever be a significant gap between America and other nations in the pursuit of STEM as there was in the past, but the American people must nevertheless work hard in order to maintain a position at the forefront of humanity's scientific efforts. Only through hard work can our nation persevere and keep up with other nations that are quickly making a name for themselves on the global stage of science.

6.0 FURTHER DIRECTION

For continued research in engineering education as explored by this project, the group would suggest that any students interested in furthering this work pursue the following topics:

1. Examine how the rigor of study and social interaction play a role in a student's interest in choosing a particular college, as well as how cultural and societal differences impact how universities operate.
2. Look into how privately funded and federally funded universities differ in their educational standards as well as the ways in which they use their funding.
3. Investigate the viability, benefits, and drawbacks of business partnerships with universities.
4. Explore the possibility of having junior or senior level university students teach engineering courses to students at the K-12 level and gauge the interest of WPI students in such a program.

There are a variety of other directions in which a future project can go and these are just a few of the questions that this project was unable to explore in the time available.

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