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American education systems in a global context

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ABSTRACT

This paper discusses the co-evolution of global and national knowledge networks. Particular attention is given to policy implications for American education; international competitiveness in math, science, and technology; and the shortcomings of American performance in these fields. The education and science policy decisions of the United States, India, and China are major determinants of each country's ability to advance knowledge and enhance the well-being of major portions of the world's population, with outcomes affecting not just residents in these countries but those beyond their borders as well. Each of these countries has its own historical and cultural education policy framework, yet there is considerable overlap among their knowledge production systems, as students and scholars increasingly participate in global knowledge networks. In turn, these interwoven networks help to shape national knowledge production systems.

1. Introduction

The education and knowledge production decisions of China, India, and the United States will be major determinants of each country's ability to advance world knowledge and enhance the well-being of major portions of the world's populations. The combined populations of China, India, and the United States total roughly 2.75 billion people, about 40% of Earth's total population, and if these three largest nations can design and implement educational systems that educate their populations in the realms of science, technology, global awareness, and critical creative thought, not only will quality of life in each of these population centers likely improve, but the well-being of many of the world's peoples beyond the borders of China, India, and the United States is likely to be enhanced significantly as well.

China, India, and the United States have each made major, though different, policy commitments for enhancing the quality of education and quantity of educated residents within their borders. At the same time, many of the educational institutions and the education policy makers in these countries are engaging proactively beyond their borders and becoming part of transnational education networks of prolific cooperation and intense competition that inform, and can even transform, national education policies and practices. We know from work in science studies and the sociology of science both that science is advanced largely through networks of practice, and that the context of these networks matters [1–4]. Thus, we must consider the ongoing development of national knowledge production networks in a global context and consider global knowledge networks in national and local contexts.

In this paper, we argue that the co-development of national and global knowledge networks should be examined explicitly as we consider our national educational policies [5]. We acknowledge, however, that these networks are not all of a piece, that each area of knowledge production has its own subculture, and that each local subculture (e.g., Silicon Valley

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versus Route 128, or Bangalore today) has its own characteristics [6], which a comprehensive analysis would take into account [7,8].

2. Linking science, technology, and education policies

To understand educational policies, systems, and institutions in the United States, and how they relate to those of China and India, it is important to recognize that in all three nations the current political configurations and policy frameworks are, compared to Western European trajectories, still quite young and dynamic. While each builds on older traditions—China, for example, has its own long and enduring tradition of Confucian-derived educational frameworks, while both the United States and India build significantly, though differently, on traditional British models—the educational frameworks of these three nations as we now know them are still in a period of rapid development. At the same time, the influence of all three nations on emerging transnational educational networks, and on one another, is still developing.

Both broad-scale education and science and technology education have relatively recently become central to national competitiveness. For thousands of years, nation states and their precursors competed principally on a military basis for economic, social, and natural resources. Even though technology and innovation had major consequences for national outcomes they were generally not systematically pursued, and human capital concerns were focused more on brawn than on brains or education.

Over the last 50 years a deepening consensus has emerged that science and technology are major drivers of national economic growth and competitiveness [9–11]. The success of scientific and technological ventures, including those centered in teaching, learning, and research institutions, have yielded many economic and social changes that have improved the overall quality of life for huge segments of the world's population while also generating significant and heretofore unknown stresses. The centrality of science and technology to economic and social advances (as well as to these new stresses) has, in turn, helped push educational policies to the forefront of policy discussions in both developed and developing countries. There is now widespread acknowledgment that our children must be prepared to participate in an economy that relies heavily on science, technology, and innovation [12]. US educational policies have, at various stages and especially over the last 50 years, attempted to address this imperative within a framework that has been shaped by a unique historical trajectory to emphasize equal educational opportunity, decentralization, and competition.

The lessons learned in the 20th century from more direct linkages of science and technology to nationally established military and economic gains, led government leaders to focus on education, and particularly science and technology education, as a mechanism through which creativity, adaptability, and economic and political development might be advanced deliberately [9,10,12]. The acknowledgment that thoughtful planning of education and science and technology development create improvements in adaptability and economic power is now considered a fundamental component of international competition in its twenty first incarnation [12]. At the same time, through the reduction of physical and technological barriers that in the past impeded travel and communication, a new environment has evolved in which political, economic, and social change move at an accelerated pace, demanding shorter planning and implementation cycles for policy. The reduction of barriers to transportation and communication has also accelerated the production and distribution of knowledge, creating to a global economic environment that is characterized by increasing adaptability, competition, growth, and connectivity.

3. The state of the American education and research system

To understand how the US education system could change as a result of increasing engagement in global knowledge networks, and in particular as a result of developing interactions with the education systems of China and India, we must first understand some fundamentals of the American policy framework.

The organizations, institutions, and policies associated with the American education system are unusually diverse, having developed largely in response to local concerns. They are a collection of entities and processes, which are dynamic and impressive, but also in some ways immature and ineffectual. Significant historical drivers that have resulted in the system that now exists and that we will focus on are: (1) universal access to education, (2) local and independent governance, and (3) competition at all levels. While these three drivers are derived from applications at the K-12 level, they set the tone for the culture of education in the United States as a whole and thus also affect the nation's framework for higher education.

3.1. Universal access to education

The concept of universal access to education, and its corollary of equality of opportunity via education, have—at least since the leadership of eighteenth century founders such as Jefferson and Franklin—been core ideals of US education and social policy [13,14]. Although over time the contours of this concept have been honed through its application in highly variable, complex social settings throughout the country, the overall objective is that all Americans will be educated to the secondary level and increasing numbers will be educated to a post-secondary level. For example, in 1862 the federal government undertook a major initiative in support of public post-secondary education: President Lincoln signed the

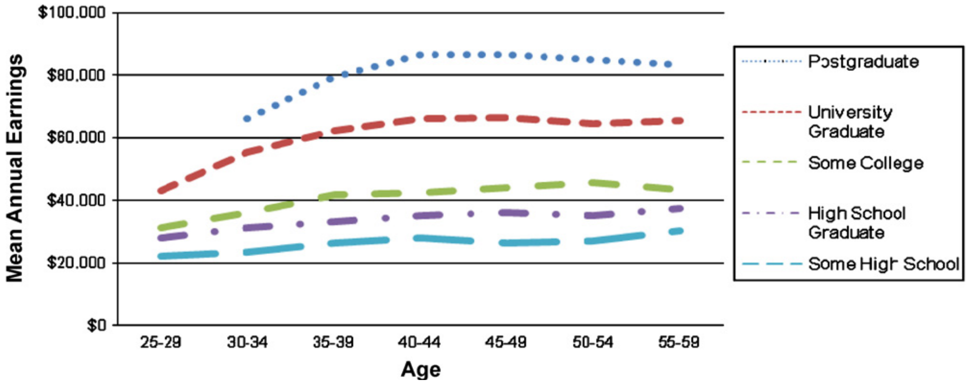

Fig. 1. Mean annual earnings by age and educational attainment in the US, full-time, year-round workers, 2002–03. *Source*: [16].

Morrill Land-Grant College Act, giving each state 30,000 acres of land for each of its members of Congress, on which to build colleges in support of (but not limited to) ''agriculture and the mechanic arts.''[1] Over time, this led to the creation of 106 colleges and universities and was also the basis for establishing the cooperative extension program, funded by the Federal government at more than one billon dollars a year, that provides technical assistance at a local level from the land-grant colleges' research programs to farmers in every state. The existence and persistence of the objective of access as a fundamental precept of American education policy is significant even in the light of any calculation of success or failure in implementation of additional or related objectives.

Although the ideal of equal educational opportunity extends to the tertiary level, post-secondary education is of course not compulsory and is usually expensive, sometimes prohibitively expensive, for students and their families. Moreover, some colleges and universities have a persistently elitist mentality. Thus, the application of egalitarian concepts and policies has been much more uneven at the post-secondary level. There are still significantly fewer students entering university-level education than those completing secondary school [15]. In its application at the tertiary level, the egalitarian principle shifts from universal access to equal opportunity for access. On successful application at the tertiary level it can produce high levels of social mobility through individual economic advancement (see Fig. 1).

3.2. Local and independent governance of education

Another important consideration within the context of this analysis is that the American national government does not impose the kind of control over education policy that it does over other areas such as defense or economic policy. While there is a US Department of Education, it is not a central ministry for education that oversees all related national and local services. And while there are certain national, or at least state-wide, standardized tests prompted by the No Child Left Behind Act [17] and in the privately funded college aptitude and achievement tests and related consortium-developed tests, there is no comprehensive system to guide students from middle school to high school to college and to create national tracks based on academic performance. From its roots as informal associations of separate colonial states leading up to the circulation of the Articles of Confederation in 1777, the American republic has been largely a federation of states, further decentralized into county and local governments, and in few arenas is this more the case than in education.

As an example, consider that the current American K-12 (primary and secondary) system of institutions has more than 13,000 independent, legally structured school–district governing bodies—mostly governing boards—that hold substantial control over the design, administration, and outcome of K-12 schools in the US [18]. These school boards are generally led by elected groups of residents who hire a superintendent, who in turn is responsible for hiring principals, who then, within the limitations of state civil service laws and school board policies and budgets, hire the teachers. This group of community members has the final say (within broad educational objectives set at the state level) over everything from the school district's curriculum to what will be served as a school lunch or provided in vending machines in the halls. These 13,000 'mini governments' have hugely divergent views regarding the purpose of education and what constitutes a good educational environment, and they each function independently according to the dynamic forces of the communities in which they reside.

Not surprisingly, attaining national educational objectives through a network of primarily independent local school boards is almost impossible. While local school boards may recognize national objectives and may potentially make adaptations, it is a very different process from the management of schools by a national ministry of education, as is the case in much of the rest of the world. This ethos of institutional diversity and local control is an important defining

[1] See Michael L. Whalen, ''A Land-Grant University,'' Cornell University Financial Plan, 2002, for an informative description of the creation, development, and current status of one major university that started as a result of the land-grant program. Whalen's essay is available at 〈http://www.cornell.edu/landgrant/resources/Land_Grant_Univ_Whalen.pdf〉.

characteristic of primary and secondary education in the United States. At the tertiary level, American institutions are governed in even more diverse ways and have numerous public, private, and special constituencies with which they engage. They do not serve under the guidance of a national education policy, and in many states serve for most purposes entirely under the guidance of their own governing boards. As a result, American universities and 4-year colleges are highly diverse, and this relatively independent governance structure means that the institutions chart their own courses and enjoy greater variability in their program design and operations than do many of their international peers, although US institutions are joined and directed in competition for federal government agency and private resources.

3.3. *Competition at all levels*

The American education system is, and has been for some time, characterized by competition. At the K-12 level in some states in the US, students may attend any public school or publicly supported charter school in any district, regardless of residence, which from an operational and a design perspective allows many families to "vote with their feet" (either by commuting or by moving) for the educational experience they desire. Thus, many school districts now effectively compete against one another for students and consequently, for precious resources. This competition has the potential to lead to great success achieved in a great variety of ways, but it can also lead to significant imbalances in the provision and quality of education as well as in the distribution of resources [19]. These inequities are often left to be addressed in the post-K-12 environment, be that a work environment or a post-secondary educational environment.

At the university level, the competition is multi-faceted, international, and intense. There are no national salary scales, no national policies that define how faculty will be recruited and hired or retained, and no national allocation of bloc grants (after land grants) on a regular and strategic basis (Congressionally funded "earmarks" or "pork" occur irregularly on project-specific bases). As a result, universities must compete openly for the best faculty, the best students, the most desirable donors, and the most sought-after research funding. In addition, the athletic competition across dozens of sports among many universities, including Ivy League institutions, is intense, dramatic, and can sometimes affect the institution in ways that go far beyond the playing fields and stadiums.

Together these three historical drivers—universal access to education, local and independent governance, and competition for funding, faculty, and students—make for a system that is, and will likely continue to be, highly dynamic. This system is also subject to an environment of rapid change and emerging stresses. It is arguably very successful at its highest levels, and marginally successful at its lowest levels.

These three drivers should be considered as part of the core context for analysis of national education trajectories in the US as we explore the many other factors that contribute to the outcomes of the educational and knowledge producing systems of the US, including demographic shifts, the changing roles of research universities, and emerging international linkages.

4. The challenges and opportunities in the US education: a focus in higher education

The principal characteristics of competitiveness and independence continue to encourage variation and adaptation within the university research community, but they have not yet encouraged major adaptations of the teaching functions of the university commensurate with the challenges related to demands for access to a university-level education. The majority of US research universities have retained the traditional, elite, student-body model, which fails to address the increasing demand for science and technology-driven education in rapidly efforts growing areas.

For the most part, the US Department of Education (DOE) is engaged in critical but arguably marginal policy issues and focuses efforts primarily on improving universal access to education in particular through investments for financial aid for college students and special programs such as those created in public elementary and secondary schools by the No Child Left Behind Act (popularly known as NCLB). But, even as the US DOE administers programs enacted separately from time to time by Congress, there is no coordinated exploration of what the education system as a whole should do to address the increasing demand for science and engineering education that is resulting from the combination of expanded access and demographic shifts.

Efforts such as NCLB have achieved some success in overcoming disparities in the performance of minority children, and have centralized some elements of the distributed system of independent governance that exists in US education, but the successes have arguably been marginal, achieved at great cost to other goals of the system (such as by fostering "teaching to the tests" to the neglect of other educational objectives), and intrinsically not capable of being repeated more than a few more times. Meanwhile, there are major changes in demand and in institutional responses already underway at the tertiary level, advancing largely by separate and varied efforts.

Demand for educational opportunities at the tertiary level is increasing and, even while more than 40% of American tertiary-level students are attending community college, the demand for a 4-year, university-level education is skyrocketing in many areas of the country [20,21]. These demographic shifts are pushing simultaneous institutional diversification and expansion within the higher education systems of the United States. The approach to this expansion and differentiation is distributed and decentralized, with each institution or region determining its own path of institutional development and in its own way engaging with expanding student populations, increasing demand for linkages with industry though research and technology transfer, and internationalization.

4.1. Demographic shifts

The United States, China, and India are all facing major internal demographic shifts and a resultant need to continue to expand and enhance their national education systems. The population of the United States is currently over 301 million and some estimates indicate that the population could increase to 400–450 million people by 2040 [22]. In elementary and secondary education significant population growth and diversification continue to cause demographic stresses, albeit on an uneven basis, as high growth states are experiencing substantial difficulties in providing quality education as needs increase faster than resources [23]. The combination of population growth, significant population mobility within the country, and immigration—internationalization from another angle—continually exerts new stresses on the K-12 education system. Considerable innovation and organizational creativity are being applied in some places to these issues at the K-12 level, but without any large-scale dramatic improvement in performance to date. For the foreseeable future, it

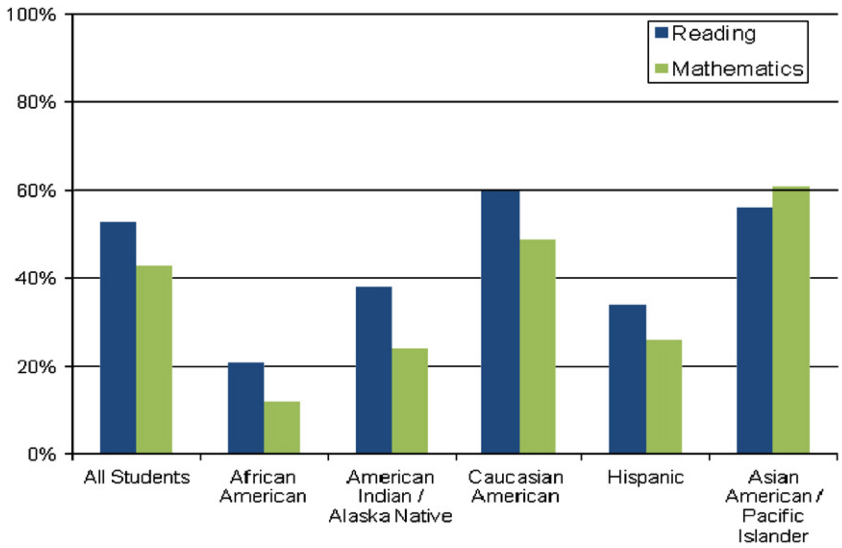

Fig. 2. Percent of ACT test takers scoring above benchmark score. *Source*: [24]. *Note*: The values shown represent the percent of students that tested above the benchmark score in reading and mathematics. The benchmark score represents the typical score of students that have a 75% chance of earning a C or higher or a 50% chance of earning a B or higher in relevant ''credit-bearing college courses.''

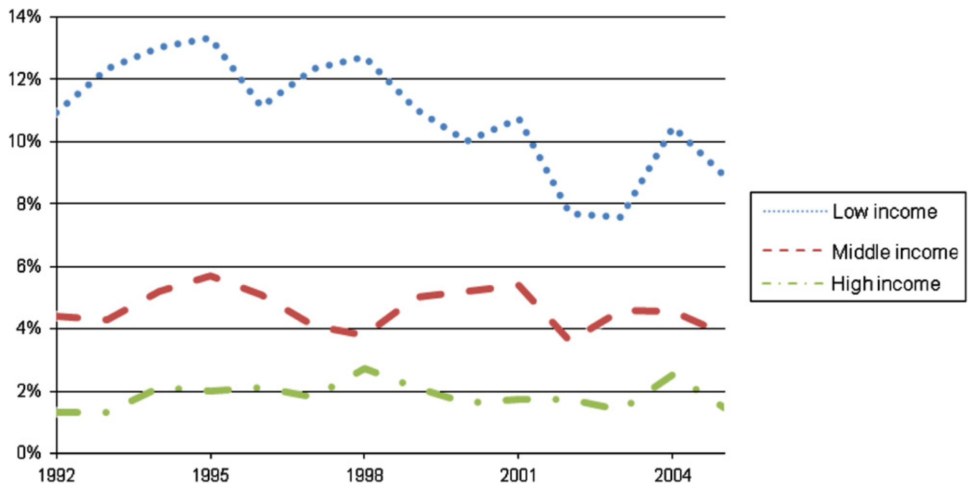

Fig. 3. Event dropout rates of 15–24 years olds by family income, 1992–2005. *Source*: [25]. *Note*: Low-income families are defined as those whose annual income falls within the bottom 2% all family incomes; middle-income families fall within the middle 20–80% of all annual family incomes; high incomes are those that fall within the top 20% of all family incomes. An ''event dropout'' is defined as a youth, aged 15–24 years old, who left grades 10–12 without a high school diploma or equivalent credential. Estimates since 1994 reflect the implementation of a computer-assisted interview system.

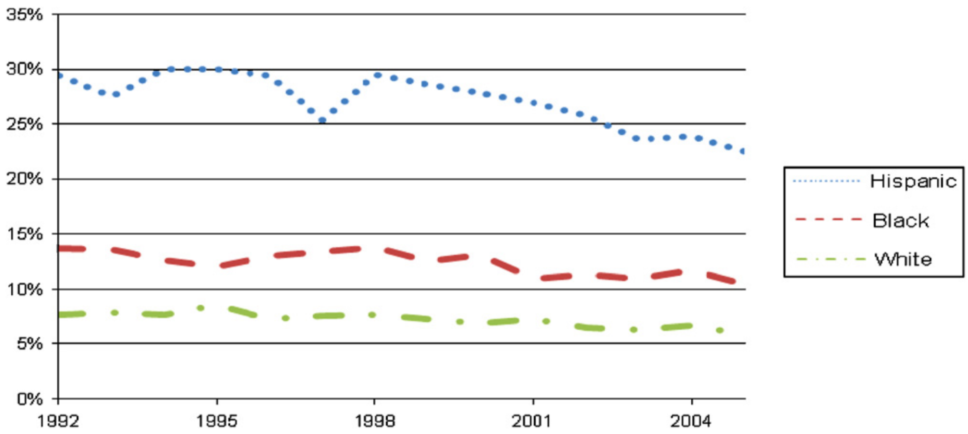

Fig. 4. Status dropouts by ethnicity, 1992–2005. *Source*: [26]. *Note*: "Status dropouts" are defined as civilian, non-institutionalized 16–24 years olds who are neither enrolled in school nor have a high-school credential.

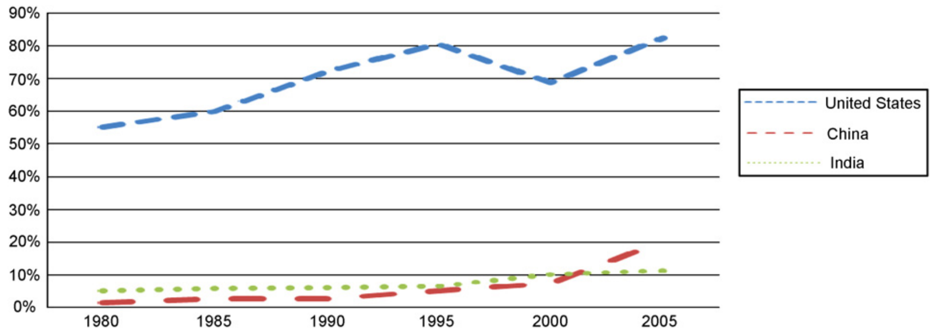

Fig. 5. Gross tertiary enrollment rate by country, 1980–2005. *Source*: [27]. *Note*: The gross enrollment ratio is the number of students enrolled in tertiary education, as a percent of the population of the five-year age cohort completing secondary school.

appears that the United States will continue to struggle with the issues of growth, mobility, diversification, immigration, and the realization of its fundamental commitment to universal access (see Figs. 2–4).

In addition, the rapid development of the American higher-education system over a relatively brief period of time, coupled with the lack of any adequate national strategy to accommodate growing demands, presents a formidable challenge for generating adequate college capacity. Meanwhile, China, and in different ways India, are expanding their capacity at the tertiary level in terms of the quantity and quality of educational and research institutions and programs, although the success of these efforts is not yet clear (see Fig. 5).

4.2. *The student pipeline: K-12 science and math education in the US*

Even without a coordinating body at the federal level, and often without coordinating bodies even at the local level to align state universities with state K-12 systems, universities must address the student pipeline—the K-12 system. In particular, given the importance of science and technology literacy for an increasingly global workforce, universities must engage and address the state of science and math education in the K-12 system. The improvement of K-12 science and math education in the US is a complex issue and, for the most part, a poorly understood area of our nation's education system. The US produces large but possibly decreasing numbers of scientists and mathematicians and very large numbers of well-trained individuals, many of whom come from all over the world to study here. However, a societal bifurcation exists between those who are well trained in math and/or science and those who are not. This bifurcation could lead not only to a decrease in national competitiveness, but also to a class separation within the citizenry. Data that show the US is under-performing compared to other countries in terms of math and science education are not hard to find (see Fig. 6). Although there are questions about the comparability of student cohorts, the results are disconcerting nonetheless [28].

Aside from any inconsistencies in testing procedures, the US has not adequately enhanced its math and science education standards in step with the technological advancements of the world [30]. While simple arithmetic may have been a satisfactory base level of education for the period when the great majority of jobs were to be found in agriculture, or later in manufacturing, this is obviously not the case now that the service sector and knowledge-based industries predominate. As the modern world continues to grow in complexity and competition globalizes, higher levels of scientific,

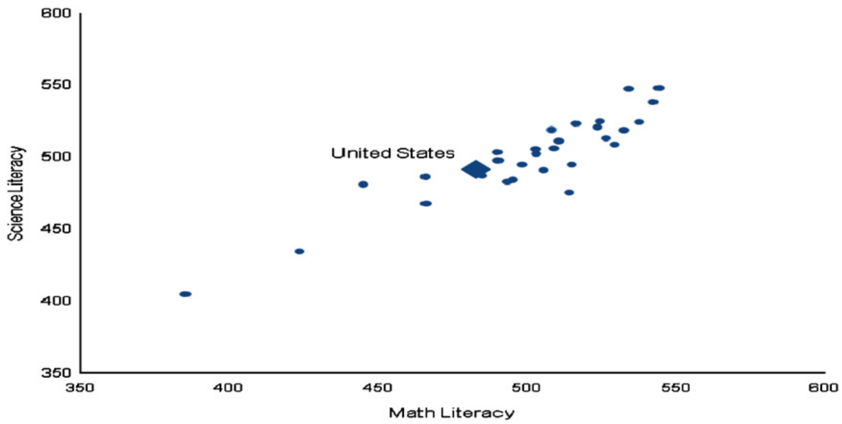

Fig. 6. Mathematics and science literacy scores of 15-year-old students in OECD countries, 2003. *Source*: [29]. *Note*: Possible test scores range from 0 to 1000. The scales were designed to have an average score of 500 and a standard deviation of 100.

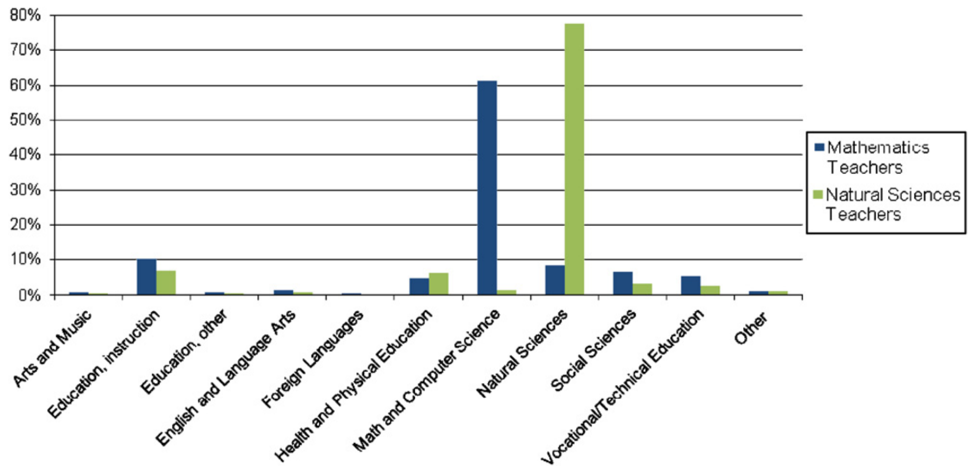

Fig. 7. Percent of high school mathematics and natural science teachers by undergraduate degree, 2003. *Source*: [32].

mathematical, and technological understanding will be necessary for an increasing number of average citizens to be employable and successful. In order to address its under-performing K-12 science and mathematics education, the US must improve three major issues: teacher preparation, global awareness, and creativity.

4.2.1. Teacher preparation

The US has too many insufficiently trained mathematics and science teachers and has not managed to retain sufficient numbers of well-trained members of the teaching workforce [31] (see Fig. 7). Science changes quickly and in order to teach it well, science instructors even in the early grades must remain not only highly motivated and competent to teach children, but also technically knowledgeable—not to the same degree as those who have been trained to become scientists or engineers, of course, but sufficiently to convey basic understandings to all students and to stimulate further those who have the potential to go on in these fields. Furthermore, at the secondary school level and beyond, science teachers who have not worked as active scientists in a venue where research is driving the daily trajectory of the discipline can sometimes have a difficult time keeping abreast of innovation and discovery. In the realm of math education, the United States has not dedicated enough attention to devising how to teach math to non-mathematicians who nevertheless will have to make some use of quantitative methods. Students lacking natural mathematical talent (or even inclination) need to be taught math by people who know how to teach individuals beyond just the mathematically gifted, while math for prospective scientists and engineers might best be taught by those who are not only dedicated teachers, but who are also professionally qualified in the fields they are teaching.

4.2.2. Creativity

American math and science education also needs a stronger emphasis on creative thought. One of the hallmarks of American education at every level is the focus on creative and independent thinking. All too often, creativity and context are absent from math and science instruction, replaced by rote learning. The result is that too many talented students are "turned off" by the subject and focus their attention on other topics that offer creative students more opportunities for intellectual originality. In order to help regain some of the interest and performance that has been lost in these areas, we must look for ways to reintroduce creativity in the teaching of math and science. While these are not the only factors affecting our nation's underperformance, they are some of the most significant.

4.2.3. Global awareness

The US needs more awareness, within its local systems, of relevant global competitiveness issues. As indicated previously, the governance of the American K-12 enterprise is designed, funded, and administered locally, and not all school districts have the same priorities. A district in rural New Mexico or another in the inner city of Detroit may self-determine that it has far more immediate and tangible issues to address on a primary-needs basis than to focus on the nation's competitiveness in math and science. For the future achievements of American students and the vigor of the nation's competitiveness, incentives and increased financial support, such as adequately funding the NCLB Act, should be established for local school governing bodies across the nation to make math and science education one of their highest priorities and to make investments in support of such an agenda.

4.3. The US higher education system: institutional diversity and differentiation

With more than 16 million university and college students in the United States, the American higher education system is an immense and complex enterprise (see Figs. 8–10). It is also an enterprise that will face many additional stresses in the future. Most recognized high-performing colleges and universities in the US matured over a century ago, and their enrollments are no longer growing in any significant amount. The expansion of any higher-education system requires attention to infrastructural needs related to volume and type of education, but it also requires a re-examination of institutional priorities. Roughly 250 of the over 4200 accredited universities and colleges in the US concentrate their efforts

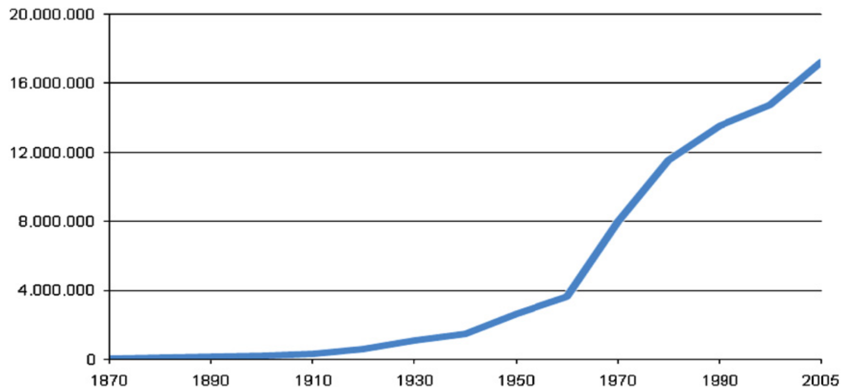

Fig. 8. Total fall enrollment at US institutions of higher education. *Source*: [33]. *Note*: Data for 1869/70, 1879/80, 1889/90, and 1909/10 are estimated. Data up to 1949/50 are for individuals enrolled any time of the year, while data after 1959/60 are for individuals enrolled during the first term of the academic year.

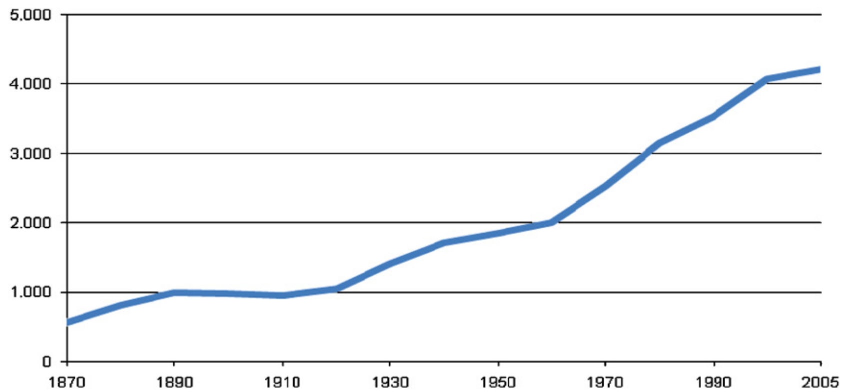

Fig. 9. US institutions of higher education. *Source*: [33]. *Note*: Data before 1979–80 does not include branch campuses.

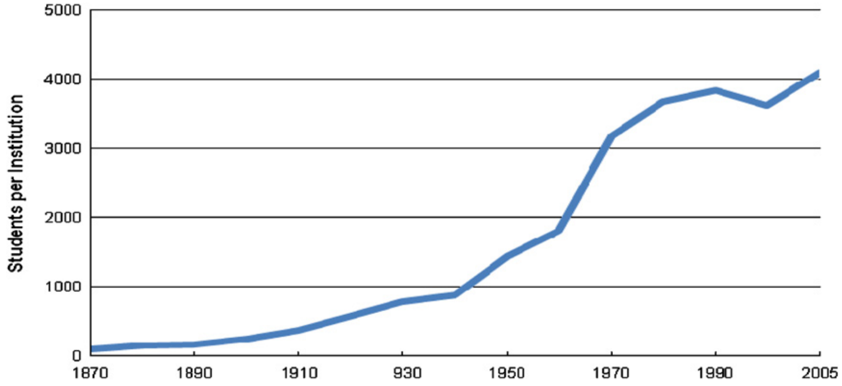

Fig. 10. Average size of US institutions of higher education. *Source*: [33]. *Note*: Enrollment data for 1869/70, 1879/80, 1889/90, and 1909/10 are estimated. Enrollment data up to 1949/50 are for individuals enrolled any time of the year, while data after 1959/60 are for individuals enrolled during the first term of the academic year. Institutional data before 1979–80 does not include branch campuses.

solely on advancing excellence at every level of their operations. A much larger number of colleges and universities instead focus on addressing the issue of accessibility to higher education. The separation between these two different missions is a source of national tension, because it leads to the *de facto* segregation of "great" students from "adequate" students and a potential separation by "education class" within American society. Such an outcome runs contrary to the underlying values of the American educational system outlined earlier in this paper and could be problematic on many fronts.

The lack of higher education planning on a national scale also makes it difficult to determine how institutions can best serve the needs of the nation as the US competes for internationally mobile capital. There is currently no workable mechanism, such as an increase in subsidies, for helping US educational institutions to educate more engineers or more math teachers. Instead, individual colleges and universities are setting their priorities and making their plans within their autonomous operating environments and financial means. The local or federal governments and business communities must then make do with potentially unsatisfactory results. Ultimately, the American system needs to work on responding to the new system not only more quickly and more precisely, but also with better-coordinated policy design.

4.4. Research universities

Of the thousands of institutions of higher learning in the United States only about 150 are considered research universities, and of these only 20 or so are among the original research universities that emerged in the last quarter of the nineteenth century [34]. These include Harvard, Columbia, MIT, Stanford, and the Universities of Michigan, Illinois, California, and Wisconsin, among others, and they remain the leading research universities today. In 1876 Johns Hopkins was the first university established as a research university. The academic research community grew by approximately 100 universities during the twentieth century and 20 of those were established in the last 50 years. While a few of the latter institutions, like the University of California at San Diego, were built from the ground up, most, such as University of California at Santa Barbara or Arizona State University, were formerly home economics schools or teachers colleges. Others, such as the campuses of the State University of New York at Buffalo and Stony Brook, developed as a consequence of the creation of a massive public university system in a state that had hitherto relied on private institutions.

Looking ahead, US research universities will play an increasingly important role in the social, economic, and cultural vitality of their regions and the nation. In addition, many of these research universities will follow the lead of the University of California at Los Angeles, Johns Hopkins University, and the University of Washington, and begin their respective transformations from the traditional research university to what we refer to as the "mega-research university." Such universities have research expenditures that total more than $750 million per year, and an extensive global presence; they generate intellectual property on a large scale, and have significant and numerous transactions with governments and industries around the world. Furthermore, it is likely that these mega-research universities will assume an important management role in the global knowledge network. These institutions reflect the emergence of an entirely new class of universities, and while we cannot predict the full implications of this development, they seem likely to be substantial.

Increased divergence among all US research universities will also be prevalent. Traditional institutions that focus around a narrow set of programs or colleges, such as Princeton, will exist side by side with very small and highly focused universities like the California Institute of Technology, specialized polytechnics like Carnegie Mellon and the Georgia Institute of Technology, the mega-universities referred to previously, and uniquely trans-disciplinary institutions like Arizona State University, the University of California at Santa Barbara, and the University of Colorado.[2]

[2] A recent article reports on a large number of new inter-disciplinary and inter-institutional research efforts brought together by a focus on global warming and sustainability. See Claudia H. Deutsch, "A threat so big, academics try collaboration." *New York Times* 25 December 2007.

4.5. Engagement with industry

During the next 20 years, industrial companies appear likely to continue to conduct less research in-house and will increasingly turn to research universities to undertake a variety of projects and programs. For example, a $500 million partnership has been established, supported by the multinational corporation BP, among the University of California at Berkeley, the University of Illinois, and the Lawrence Berkeley National Laboratory, for the purpose of developing a new set of biofuel technologies. Stanford University has also been engaged by a group of multinational corporations, including Exxon Mobil, GE, Schlumberger, and Toyota, for a $225 million project dedicated to identifying entirely new technologies for the global energy industry [35]. There are thousands of similar transactions taking place throughout the US and the frequency, size, and complexity of these joint research projects is increasing and shows no sign of slowing. At the same time, multinational corporations, including Microsoft and Intel, are increasingly investing in research at universities outside the US and building their own international networks of knowledge production. These endeavors may add complexity to the knowledge network relationships that exist among and between universities in the US, India, and China.

Some universities, such as Stanford, Columbia, MIT, University of Wisconsin, University of California, and University of Florida, have increasingly crossed the transom into the open market for developing technologies invented in their laboratories. Such technology transfer will become an increasingly important, complex, and challenging function within American universities and, we suspect, also in India and China.

5. National and global knowledge networks: merging and emerging science, technology, innovation, and education systems

The US education system appears likely to advance along a trajectory characterized by a combination of decentralization and increasing integration into international networks of knowledge production. International networking is accelerating and global educational networks are expanding in which US institutions, scholars, and students are linked in their experiences and development to foreign systems of education and international partners.

The nature of scientific research in many arenas increasingly requires distributed centers of research for knowledge production. Few institutions today can work alone in their research endeavors. Partnerships for intellectual, financial, and physical resources are required. This is particularly true as we strive to understand ever more complex and interdisciplinary research questions. Partnership networks are expanding in size and scope, bringing together researchers from institutions around the world to explore shared challenges and inquiry [39].

Major US universities are becoming institutions with heightened global focus, and are beginning to establish programs and facilities around the world on an unprecedented scale. The construction of new Ivy League medical schools in the Middle East, the expanded formal linkages (in the hundreds) between US universities and Indian and Chinese institutions, and the emergence of physical campuses in India and China shared with US universities, are further evidence of this enhanced internationalization and ongoing decentralization in the US system [36]. Collaborative relationships among universities will continue to grow and diversify, providing researchers and students with opportunities unlike any before (see Figs. 11 and 12). These collaborative relationships rely not only on international networks of scholars for their success, but also increasingly on networks of students, particularly with the rise of the interactive uses of "Web 2.0" and the emergence of Facebook and other international social networking programs.

The educational and research systems in China, India, and the US have become increasingly linked over recent decades through networks of individuals within the arenas of scientific research, technology development, and related processes of innovation [39,40] (see Fig. 13). Hundreds of thousands of scientists and engineers as well as professors, physicians, cultural specialists, and intellectuals have formed prolific transnational systems of science and technology professionals who share common understandings about the terms of knowledge and knowledge production both within and among their countries of origin. The scientists, researchers, teachers, and students who make up these global networks form a cultural bridge of

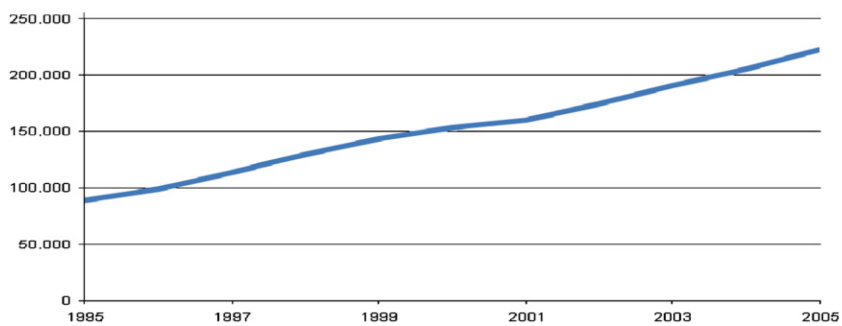

Fig. 11. US students studying abroad by year. *Source*: [37].

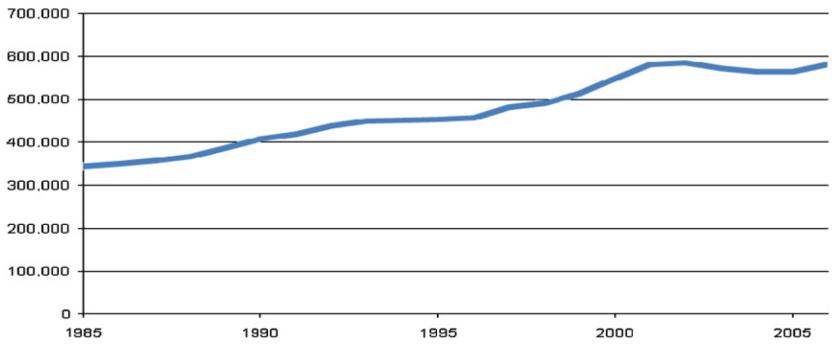

Fig. 12. International students studying in the US, 1985–2005. *Source*: [38].

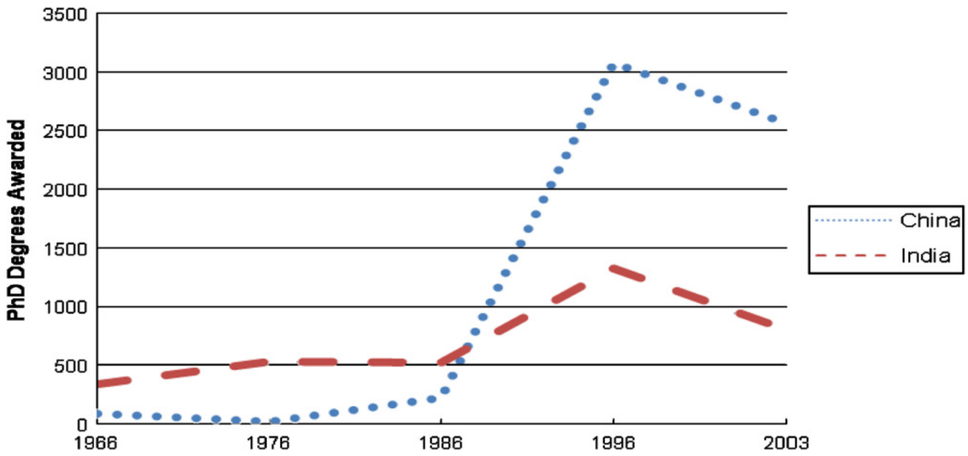

Fig. 13. US science and engineering PhDs awarded to Chinese and Indian citizens, by year. *Source*: [41].

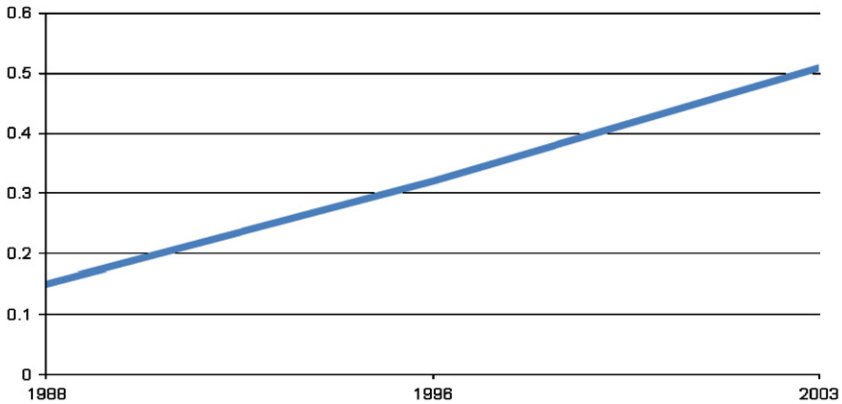

Fig. 14. Average number of foreign addresses per US S&E articles, by year. *Source*: [41].

shared experience and expertise such that within each nation there are groups of individuals and institutions that are directly informed by experience in their own national cultures, as well as in the transnational academic culture.

Large networks of Chinese-born and Indian-born scientists and researchers function at all levels of the US science and technology system, and their participation helps to form the social and intellectual fabric of the US system of innovation [42] (see Fig. 14). As China and India continue to emerge as science and technology powerhouses in their own rights, and as scholars return to the countries of their birth to work or enter into joint projects with other members of transnational personal, professional and institutional networks for knowledge exchange and science and technology development, they also often influence their native countries' science and technology systems and institutions [43]. There exist deep connections among the scientists and engineers in these three nations [39].

6. The triad: driving global change and opportunity

It is too simple to focus solely on specific competitions and collaborations among only these three nations when considering the realms of science and technology. The greater challenge is to find answers to a more comprehensive question: How can the commitments to education, culture, connectivity, innovation, and science and technology shared by these nations yield broad and positive outcomes for the population of the world?

While China and India, as well as the United States continue to progress economically, their own and neighboring developing regions remain places where social and economic advances must continue in real time and at relatively high levels of magnitude in order to enhance materially the overall standard of living among the world's people. As science and technology-focused, education-driven, internationally engaged nations, China and India are capable of producing major, positive social and economic outcomes worldwide that may serve as critical catalysts for attacking poverty and disease and bringing about rapid development on a global scale. As economic and social development continues, there is a danger that our inability to engage on a growing scale could keep social and economic development from advancing as rapidly as it might. While great progress has been made in many developing countries, it has not occurred everywhere at the speed one might expect given the levels of extreme poverty and diminished quality of life that remain in many places. From this perspective then, the US is one-third of a triad that might become one of the most significant forces for global change and advancement in history [44]. However, the role of the US in this triad is not guaranteed and our continued involvement depends to a large degree on how the American educational system continues to evolve.

7. Conclusion

The US framework for knowledge and human resource production has long been anchored by its commitments to universal access to education, local and independent governance, and a culture of competition. The application of these concepts has shifted over time and will likely require significant additional adaptation in order to meet the needs of our rapidly changing world. These anchors will be major determinants of the ways in which the American educational system will interface with global knowledge networks. As US universities, and even in select cases K-12 schools, increasingly interact with their counterparts in China, India, and beyond, these interactions will substantially shape the US's trajectory in education, science, and technology. We need to continue to explore the web of strong and weak ties that together interweave the global, national, and local knowledge networks that generate new knowledge and innovation. The better we understand these networks and their interrelationships, the better able we will be to develop effective education and innovation policy at all levels. The betterment of the human resource base of the US, and the country's capacity for knowledge production, will be determined by its ability to design and implement new educational policies, systems, and institutions that can successfully integrate the historical drivers of American education with new forces of international collaboration and competition.

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