NBER WORKING PAPER SERIES

INNOVATION AND AMERICAN K-12 EDUCATION

Aaron Chatterji

Working Paper 23531
http://www.nber.org/papers/w23531

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
June 2017

This paper was written for the NBER Innovation Policy and the Economy Forum on April 18th, 2017. I am grateful to Josh Lerner, Scott Stern, and Yasin Ozcan for helpful comments. I also benefited immensely from my conversations with Benjamin Jones, Wesley Cohen, Kevin Bryan, and Ashish Arora on this topic. Boya Xu provided excellent research assistance. All errors are my own. The views expressed herein are those of the author and do not necessarily reflect the views of the National Bureau of Economic Research.

Innovation and American K-12 Education
Aaron Chatterji
NBER Working Paper No. 23531
June 2017
JEL No. H52,I20,I21,I28,O30,O32,O38

ABSTRACT

Economists have long believed education is essential to the acquisition of human capital and contributes to economic growth. However, education researchers, political and business leaders and other stakeholders have raised concerns about the quality and costs of the K-12 education system in the United States and the implications for the development of the nation's future workforce. Some of these groups have called for more innovation in K-12 education, leveraging technology in the classroom and experimenting with different organizing models for schools, both as a means to lower costs and increase quality. To shed light on the prospects of this approach, I review the economics literature at the intersection between innovation and K-12 education from two different, but related, perspectives. First, I summarize the evidence about the efficacy of technological and other kinds of innovation in the classroom. Second, I discuss the state of research on how the American K-12 system influences the production of innovators and entrepreneurs. In both instances, I identify implications for policy and opportunities for future research to generate actionable insights, particularly around increasing the low levels of research and development in the education sector.

Aaron Chatterji
The Fuqua School of Business
Duke University
100 Fuqau Drive, Box 90120
Durham, NC 27708
and NBER
ronnie@duke.edu

Introduction

A key objective of public policies designed to promote innovation is to develop, attract, and incentivize individuals who will generate new technological ideas. Much of the economics literature in this domain has focused either on increasing the "intensive" margin of innovation from the ranks of existing inventors via incentives and intellectual property policy (c.f. Stern 2004; Jaffe and Lerner 2011; Bell et al. 2016) or on contributing to the "extensive" margin via high-skilled immigrants, who have been found to contribute disproportionately to U.S. innovation and entrepreneurship (e.g., Saxenian 2007; Kerr and Lincoln 2010). However, economists have written far less about specific policies that can add to the extensive margin of innovation from a different source, namely, developing the innovative and entrepreneurial potential of the native-born population.[1]

The priorities of different sub-fields in economics partially explain this gap. Although education economists have studied the American K-12 education system extensively, they have rarely assessed innovation-related metrics, focusing instead on broader outcomes such as test scores and graduation rates. For their part, innovation economists seldom study the K-12 education system directly, but rather favor studying innovative outputs of firms, universities, and governments. As a result, we still have much to learn about how education policy can affect the domestic supply of innovators and whether new technological innovations can improve K-12 educational outcomes. Some quite recent academic work, discussed below, provides some intriguing insights for policymakers. However, the relatively small number of papers and

[1] There is existing work on innovation and entrepreneurship policies that looks at developing geographic regions, reviewed by Chatterji et al. (2014). Other scholars have explored the role of higher education in producing an innovative workforce (e.g., Romer, 2000; Stephan et al. 2004).

numerous remaining open questions underscore an emerging opportunity for economists interested in the intersection between innovation and education.

In this paper, I review two strands of literature that relate to the nexus between innovation and education. First, I examine the small literature in economics that typically uses experiments to evaluate the impact of technology (hardware and software) on student achievement. I also briefly summarize the implications from work on how organizational innovations, such as the promulgation of new management practices, are related to student outcomes. Second, I discuss the emerging literature on how the design and curriculum of education systems relates to the production of an innovative workforce.

Technology, Productivity, and Schools

The economics of innovation has a long tradition of estimating the productivity benefits from adopting new information technology (e.g., Stiroh 2002). Although technology has enhanced productivity across various industrial sectors, it has arguably not had that effect in K-12 education, despite the great expectations of policymakers, the media, and some technologists. Cutler (2011) reports that productivity growth in two key sectors, education and healthcare, grew quite slowly after 1995, in sharp contrast to the economy as a whole, where numerous industries leveraged new technologies effectively. These two sectors feature prominently in research on the "cost disease" (Baumol and Bowen 1966; Baumol 2012) which argues that costs can rise rapidly in industries with low productivity growth, in part because of key services that are particularly reliant on humans. It is worth noting here that just as Cutler (2011) provides a framework for understanding where innovators and entrepreneurs can drive productivity increases in healthcare, a primary aim of the discussion below is to address similar questions with respect to K-12 education. In doing so, I seek to direct the attention of innovation scholars to a new context, which, much like healthcare, features significant government involvement and complex regulations.

Several reasons could explain why education has not experienced rapid productivity gains via technology adoption to date. First, the supply of high-quality technologies might be limited in comparison to other sectors, due to low investment in research. R&D accounts for a tiny share of total expenditures in K-12 education, around 0.2%, or 1/50 the rate of the most innovative industries (See Figure 1). This low level of investment is even more striking when one considers that total K-12 spending is approximately $600 billion a year, which is similar to expenditures in R&D intensive industries such as pharmaceuticals (Chatterji and Jones 2012). Further, given that improving education is typically considered an important national priority, alongside goals such as enhancing public health, increasing national security, and discovering more sustainable sources of energy, it is conspicuous that the U.S. invests so little in education R&D in comparison to these other areas.

What can explain this low level of R&D? The private value from commercializing innovations for use in K-12 schools could be low. However, at first glance, this explanation seems at odds with the facts. The market for education technology hardware and software in the United States is actually quite large. Prior work by Chatterji and Jones (2012) argues that it is the market structure, as opposed to the size, of the sector that makes it difficult for innovative entrants to thrive, stunting the development of new technologies, a proposition discussed further below.

Another, not mutually exclusive, possibility for the lack of IT-related productivity gains in American schools is that these organizations face endemic management challenges that hinder the adoption of promising technologies that could increase student achievement. Under this logic, productivity-enhancing technology is available, but organizations are not adopting it, whether from fears over substitution of labor for capital or disrupting existing curriculum. If this explanation were a key factor, we would expect to observe different management practices and technology-adoption rates across various kinds of schools, for example, between private and public schools, which differ in terms of flexibility and incentives. We review some indirect evidence on this point below, though it does not appear private schools are clearly more effective in their use of technological tools in comparison to public schools on average.

Understanding Technology Adoption in Schools

To develop a deeper understanding of what makes education technology distinct and to resolve the puzzles posed above, we can leverage prior work in economics on technology adoption by firms. For both firms and schools, a classic information problem arises when deciding whether to adopt a new technology. Many new technologies have difficulty in demonstrating efficacy, particularly across heterogeneous customers, whether those customers are different kinds of firms or different kinds of schools. Without institutions to facilitate transparency about the efficacy of particular technologies, organizations that could benefit from a new technology still might not adopt it.

In other key respects, the technology-adoption decision for a school district is markedly different from that of a private sector firm. For example, how a typical public school would necessarily capture the gains from adopting a technological tool that improved student outcomes is not clear. Whereas firms can use new technologies to lower costs or improve product features, for example, public schools do not seek profits and do not generally compete for students in the same way firms compete for customers. Thus, the incentives to adopt technology from a pure return-on-investment perspective are attenuated.

Another key challenge is related to the market structure of K-12 education. Approximately 100,000 public schools and over 30,000 private schools are in the United States,[2] and they are characterized by diverse preferences. The majority of decisions pertaining to schools are made at the local level and, with the exception of efforts such as the Common Core Standards, curricular choices can vary widely across the country. The result is, despite 100,000 potential customers, demand for education technologies is not sufficiently aggregated.[3] Designing technological tools in the absence of aggregated demand is challenging. For an innovator comparing the expected value (V) from successfully commercializing an innovation with the cost (C) of developing and selling it, this lack of aggregated demand implies the costs, due to implied customization for each idiosyncratic customer, are much higher than when customers are more homogenous. As C rises, assuming no increase in V, the incentives to develop innovation are weakened, limiting the number of high-quality products available.

Another important feature of this setting, as discussed in Chatterji and Jones (2012), is that the instructional content market in education is dominated by three large textbook makers. Perhaps surprisingly, 70% of pre-K-12 instructional content today is still printed material.[4] These textbook companies leverage their large marketing and sales efforts to sell complementary education technology, in many cases tied to their textbooks. This market structure, coupled with the lack of institutions to independently assess efficacy, depress the expected value (V) for an innovator with a new technology. If the technology cannot be demonstrated to be effective, who will adopt it? And even if a handful of schools adopt the tool, how would the innovator scale

---

[2] The National Center for Education Statistics (https://nces.ed.gov/fastfacts/display.asp?id=84). Last accessed March 28th, 2017

[3] Large school districts, including the top five school districts which serve nearly 3 million students combined, do represent at least the potential for aggregated demand. See Chatterji and Jones (2012).

[4] "How are Digital Materials Used in Classrooms?" (http://www.edweek.org/ew/issues/technology-in-education/#distance).

these efforts to capture a larger part of the market? These uncertainties are one reason rates of R&D spending and venture capital investment in education technology products might be comparatively low relative to the total size of the addressable market. As shown in Figure 2, investment is K-12 education-technology ventures was $741 million in 2015 compared to nearly $60 billion across all industries in the same year.[5]

The discussion above suggests the market structure in education and the complex process by which schools adopt and implement new technological tools can explain why this sector has not experienced dramatic productivity gains from IT. These themes will frame the next section of the paper, where I review specific studies of how innovation affects student performance and other related outcomes.

The Impact of Technology on Student Performance

Federal policymakers have long emphasized the importance of providing computers and internet access in the classroom. For 15-year-olds in the United States today, the ratio between computers and students is almost one to one (Bulman and Fairlie 2016). The E-rate program, launched in 1998 and budgeted at $3.9 billion in 2015,[6] provides schools and libraries with discounted internet access (Goolsbee and Guryan 2006). In part due to this program, nearly every classroom in the United States has internet access (Fairlie et al. 2010), and 88% of school districts have high-speed broadband as of 2016, defined as 100 kbps per student.[7]

---

[5] "$58.8 Billion in Venture Capital Invested Across U.S. in 2015, According to the MoneyTree Report," NVCA Press Release, January 15, 2016. (http://nvca.org/pressreleases/58-8-billion-in-venture-capital-invested-across-u-s-in-2015-according-to-the-moneytree-report-2/).

[6] Wyatt, Edward. "F.C.C. Increases Money for E-Rate Program for Internet in Schools and Libraries" The New York Times, December 11th, 2014. Last accessed February 26, 2017.

[7] EducationSuperHighway. "2016 State of the States" January 2017 (http://stateofthestates.educationsuperhighway.org/).

The market for education technology in the United States is estimated to be approximately $8 billion a year.[89] A proliferation of technology has emerged in American schools in recent years, with schools spending significant sums on hardware such as tablets and laptops, interactive “smart boards,” teacher training, and digital curriculum.[10] Significant sums have also been spent on enterprise-software-style solutions designed for managing student information and a large “after-school” market for mobile education applications. For one data point that reinforces the scale of this market, consider that Apple’s App Store currently has 170,000 different education applications.[11]

Proponents of greater use of technology in the classroom generally posit the following mechanisms by which student performance can be increased via the introduction of technology. First, as Barrow et al. (2009) articulate, technology might improve student performance by facilitating more hours of high-quality individualized instruction time. The authors discuss how access to computers and appropriate software can facilitate “personalized learning” whereby the education content is provided at a level appropriate for the student and consistent with the student’s preferred mode of instruction. According to this logic, personalization could theoretically increase outcomes for high-performing and low-performing students. An ancillary, but possibly important, benefit is that using technology in the classroom could also allow teachers to spend more time with each student, because a proportion of students could be

---

[8] Murphy, Meghan E. “As market surges, schools struggle to find the best tech products.” The Hechinger Report, March 24, 2015 (http://hechingerreport.org/as-market-surges-schools-struggle-to-find-the-best-tech-products/).
[9] Herold, Benjamin. “Technology in Education: An Overview” Education Week, February 5, 2016 (http://www.edweek.org/ew/issues/technology-in-education/). Last accessed February 27, 2017.
[10] EdNET Insight, “State of the K-12 Market Report 2015” (http://schooldata.com/ednet-insight/).
[11] http://www.apple.com/education/products/ (Last accessed March 31, 2017).

occupied at any one time with computer-aided instruction. This scenario poses technology as a substitute for teachers, as opposed to a complement, a possibility that is discussed further below.

Aside from personalized instruction, digitized content that can be viewed across different hardware devices can broaden access to education, for example, by providing advanced placement courses to a geographically isolated school that does not have the appropriate staff or facilities. Via this channel, greater access through digitization of content could raise student achievement. Moreover, the user interface provided by digital tools might simply enhance learning, or the mere presence of new technology in the classroom might increase student motivation and engagement.

However, despite the ubiquity of technology in the classroom and various proposed mechanisms of action, rigorous evaluations of the impact of technology on student performance are rare and the results are mixed (Bulman and Fairlie 2016). Goolsbee and Guryan (2006) find that while E-Rate increased investments in education technology between 1996-2000 in California public schools, it produced no statistical impact on student performance. This finding is consistent with other studies from the United States and around the world, which find little or no impact of technology on student outcomes (e.g., Angrist and Lavy 2002; Rouse and Krueger 2004). However, other studies have found some positive impact of technology on student performance (Ragosta 1982; Banerjee et al. 2007; Machin et al. 2007; Barrow, Markman and Rouse 2009; Cheung and Slavin 2013; Muralidharan et al. 2016). As discussed in Barrow et al. (2009), these benefits must be weighed against the costs of program adoption and ongoing implementation.

Researchers have offered several explanations for this apparent disconnect between the promise of technology and mixed empirical results. One rationale, supported by qualitative assessments, is that fidelity of implementation is the key barrier. Although technology is present in the classroom, teachers and students might not use it (e.g., Cuban et al. 2001) or use it in suboptimal ways (Wenglinsky 1998). For example, some recent high-profile technology interventions, such as a $1 billion tablet initiative in the Los Angeles Unified School District, have been roundly criticized by journalists and education policy experts due to implementation challenges. In the case of L.A. Unified, serious technical issues prevented a large percentage of students from accessing the required curriculum.[12] Such examples are consistent with the idea that several important complements must be in place to leverage technological tools effectively, most notably high-quality instructors and the appropriate curriculum.

Note that if teachers and technological tools are complements instead of substitutes, the implications for productivity from a given intervention might be quite different. For example, to fully realize the benefits of a given technological tool that complements teachers, a school district might need to finance more training for its teachers or even hire additional staff, leading to increased costs, all else being equal. Contrast this scenario with one in which teachers and technology, say, tablets loaded with self-guided content, are viewed as substitutes. In this instance, substituting technology for labor might directly reduce costs.

Another explanation for the mixed results of technology interventions could be that some technological tools are conducive to learning, but we do not know which ones. So the technologies that are most widely used are not those that are actually most beneficial for students. Currently, most education technologies do not undergo any kind of systematic and rigorous evaluation, which obscures efficacy and likely decreases incentives to innovate in the

[12] Lapowsky, Issie. "What Schools Must Learn from LA's iPad Debacle", Wired. May 8, 2015 (https://www.wired.com/2015/05/los-angeles-edtech/) Last accessed March 29, 2017.

first place (Chatterji and Jones 2012). Without evidence of what works, schools adopt technological tools based on relationships with existing companies, and the sales cycles are long and complex, dampening incentives for new entrants, as discussed above. As one illustration of this phenomenon, the famous venture capital firm Andreessen Horowitz reportedly refuses to invest in any education-technology company for which a school or district is intended to be the primary customer.[13]

Chatterji and Jones (2012, 2016) argue that low-cost and rapid evaluation methods could increase entry into the education-technology sector, spur broader adoption of the most appropriate technologies, and possibly raise student outcomes. One way to think about transparent and rapid evaluation is in the context of the innovator's decision discussed earlier. If a new technology could be quickly evaluated and compared with existing products, such a process would enhance the expected value, V, to prospective innovators. Moreover, it might also reduce the costs, C, of marketing and selling the product to a diverse set of customers, because these buyers could presumably review the publicly available evaluation results directly. One further possibility is that existing demand aggregators, such as the League of Innovative Schools,[14] might have preferences for adopting evidenced-based products. The increase in V and decline in C would increase the incentives for innovation and make venture investments in education-technology companies more attractive, spurring future innovation and entrepreneurship. For a longer discussion on this point, see Chatterji and Jones (2012).

The lack of consistent benefits from technology adoption in schools might have other explanations. For example, technology could be distracting students to a greater extent than it

[13] "Catching on at last" The Economist, June 29[t] 2013. (http://www.economist.com/news/briefing/21580136-new-technology-poised-disrupt-americas-schools-and-then-worlds-catching-last) Last accessed February 27, 2017

[14] The League of Innovative Schools (http://digitalpromise.org/initiative/league-of-innovative-schools/)

contributes to learning, which would be consistent not only with the empirical results from the academic literature, but also with numerous anecdotes from school administrators.[15] In addition, technologies could be having a positive effect, but not on the skills that can be tested using traditional methods. For example, technology adoption by schools might result in a higher level of technological fluency (e.g., greater comfort with various kinds of hardware and software) that might benefit students later in life, even if it does not directly affect test scores.

Another intriguing possibility is that specific kinds of education technology perform far better than others. In one of the most recent studies on this topic, Muralidharan, Singh and Ganimian (2016) find positive and economically large results for their computer-aided learning intervention in India, prompting them to categorize the literature in this domain as follows: Those interventions that have focused on supplying hardware alone have generally not been effective. Software programs that allow students to proceed through grade-appropriate material at their own speed produce small positive effects. The largest effects, present in their study and Banerjee (2007), emerge from software interventions that tailor the content to the student's ability, consistent with the personalized learning approach referred to above.

This suggestive pattern of results across studies highlights an important gap in the economics literature: economists have done little work to understand how students learn and how variations in these styles may affect human-capital acquisition. Although a large literature in education and psychology has explored how students learn, this work has not been connected in a meaningful way to economics.

---

[15] Richtel, Matt, "In Classroom of Future, Stagnant Scores" The New York Times, September 3, 2011 (http://www.nytimes.com/2011/09/04/technology/technology-in-schools-faces-questions-on-value.html) Last accessed February 27, 2017)

Education technology that is deemed to be “personalized” to the student can have several different varieties. First, a personalized software application to teach a particular skill could simply facilitate a different pace of instruction depending on the student. Some students could move faster and others could move more slowly, which may provide some advantages over traditional instruction, where adjusting the speed of delivery to each individual student would have practical limitations. Second, as discussed in Muralidharan et al. (2016), a software application could provide personalized content that adapts depending on the student’s previous answers, providing the most appropriate level of instruction and focusing on key areas of weakness in a particular domain.

A third approach to personalization is software that is customized to each student’s “learning style,” defined by Pashler et al. (2008) as “the view that different people learn information in different ways.” Pashler and co-authors argue that although learning style is a popular concept in educational psychology and the media, little evidence to date shows they actually exist. The authors argue that to demonstrate that individuals have different learning styles, not simply expressed preferences, a researcher would have to randomly assign different styles of instruction to different kinds of students and demonstrate that “correct” matches between students and styles actually leads to better performance. More research is required to document the existence and importance of learning styles and to explore the role specific education-technology tools could play in matching students to the most appropriate content.

In terms of identifying promising technologies, some recent efforts have been made to spur increased research and development in the education-technology space. In 2010, the President’s Council of Advisors on Science and Technology (PCAST) proposed the creation of the Advanced Research Projects Agency-Education (ARPA-Ed), modeled after the DARPA program to create technology platforms and digital curriculum, spurring innovation in the education sector (Lander and Gates 2010). A key challenge for these efforts is not simply the evaluations themselves but also the method by which the results are disseminated. Although many kinds of hardware and content have diffused widely in schools, ranging from Khan Academy to smartboards, no system is currently in place to incentivize the adoption of education technology that has been demonstrated to be effective. To address these concerns, Chatterji and Jones (2012, 2016) propose a platform to rapidly evaluate digital learning activities in the classroom using randomized controlled trials. Their platform, EDUSTAR, has evaluated 77 digital learning activities to date.

Organizational Innovations in K-12 Education

Recent work in economics and other fields emphasizes another important consideration for evaluating the promise of innovation in schools: how organizations are managed. Scholars who study private sector organizations have documented that the benefits of technology adoption depend heavily on the attributes of the organization. For example, Bloom et al. (2012) argue that recent U.S. productivity gains relative to Europe were driven by better "people management" practices among American firms in industries that intensively use IT, such as retail. Because significant variation exists across schools in terms of governance, human resource practices, size, strategy, and culture, existing management practices or organizational structures could be hindering the adoption of technology.

Bloom et al. (2015) find the management of U.S. schools compares favorably to the management of schools in other nations, which is correlated with higher student outcomes. Further, charter schools have higher management scores than traditional public and private schools. This result is consistent with Angrist et al. (2013) and Dobbie and Fryer (2013) who both find a positive relationship between specific management practices and school performance measures. Relatedly, a recent field experiment by Fryer (2017) finds evidence for a causal effect of management training for principals on student achievement in Houston public schools.

Future research could further investigate the relationship between management practices at schools and the adoption and efficacy of new technologies. The findings could shed new light on how best to leverage new education technology to aid student learning. Moreover, the rise of new organizational models in education presents opportunities for research. Although a large amount of research has focused on charter schools (see Chabrier et al. (2016) for a recent summary) and school voucher programs (e.g., Ladd 2002), far less research has investigated other kinds of schools with novel organizational structures and practices, such as STEM-focused schools and virtual schools (see Woodworth et al. (2015) for an exception).

K-12 Education and an Innovative Workforce

Next, I turn to the second major stream of work in this domain, which explores the relationship between K-12 education and the creation of an innovative workforce. Economists have argued U.S. productivity growth depends in large part on the knowledge-intensive sectors of the economy, which will increasingly require skilled workers to invent and use new technologies along with developing business models to commercialize them. This demand for skilled workers has been increasing in the 21st century, as firms shift from investing in production activities reliant on tangible capital to non-production activities more reliant on intangible capital. This change will require workers who have higher levels of skills in innovation, management, and marketing (Hulten and Ramey 2015). Many political and business leaders argue that the U.S. economy lacks the requisite number of skilled workers to capitalize on these trends (e.g., Augustine et al. 2010). Figure 3 illustrates that the United States lags China and India in the number of STEM graduates per year, though many observers have pointed out that quality-based measures may be more informative indicators.

In response to these challenges, an emerging academic literature has focused on the allocation of talent in the U.S. economy and its implications for innovation. Much of this literature has focused at least in part on science, technology, engineering, and mathematics (STEM) subjects, which are thought to be particularly important inputs to innovation (Augustine et al. 2010). At the university level, some work has found an association between STEM degrees and the propensity to become an inventor (Aghion et al. 2015; Bianchi and Giorcelli 2017). Recent performance data suggest American secondary students are lagging behind peer nations in math and science achievement (Lander and Gates 2010; Hulten and Ramey 2015), a concern not only for innovation per se but perhaps also for these students' long-term employment outcomes (see Figure 4).

Although specific policies to support STEM education in the United States can be traced back to at least the 1958 National Defense Education Act, which was designed to reform the science curriculum in response to Soviet scientific achievements (Goodman 2017), only recently has a more targeted strategy emerged. In 2010, the PCAST recommended the creation of a STEM Master Teacher Corps that could provide increased salary and compensation to STEM teachers and increase the number of STEM-focused schools to 1,000 by 2020. The PCAST also called for the National Science Foundation and the Department of Education to develop a partnership and better coordinate the numerous disparate programs promoting STEM across the federal government (Lander and Gates 2010).

Fostering interest in STEM fields

Despite significant interest in expanding STEM education, very few rigorous evaluations of the impact of these programs exist to date. Some evidence suggests particular interventions can increase student interest in STEM fields. Hulleman and Harackiewicz (2009) employ a semester-long randomized controlled trial (RCT) with 262 high school science students and find that asking students to write monthly about the relevance of the course material to their own lives (compared to a control condition where the students summarize what they learn) increases student interest in science and their inclination to take science courses in the future.

Understanding how exposure to the media, mentors, and labor market signals influences students' selection into STEM fields of study and careers has also been a focus of research. Some scholars have explored how the "STEM pipeline" can break down, leading to students expressing interest in STEM early in their academic career but eventually pursuing other fields of study (e.g., Bettinger 2010). Shu (2016) examines a related conjecture that higher compensation in the financial services industry has lured away "the best and brightest" of U.S. college graduates from science- and engineering-based jobs. Using a sample of MIT graduates, the author does not find that lucrative opportunities in finance are drawing away talented would-be scientists and engineers. Shu concludes that finance and STEM jobs have different requirements and different kinds of preferred candidates and that below-average students are the ones who respond to shocks to finance salaries. Although this study uses post-secondary education as an empirical context, the perception of job opportunities might influence investments in STEM education in secondary schools as well.

The impact of STEM on earnings

Next, some evidence is emerging on the extent to which STEM education affects earnings and the generation of new inventions later in life. Goodman (2017) finds evidence that an exogenous increase in math coursework during high school increased African-American student earnings by 3%-4%. This study is especially notable because most of the prior literature in the economics of education focuses on the amount of *time in school*, as opposed to the subjects over which that *time is allocated*. This point implicates a key concern in most studies aiming to establish a connection between STEM courses and long-term outcomes. High-ability students may select into STEM courses, confounding the relationship between these courses and outcomes such as earnings, innovation, or entrepreneurship. The most useful studies will be those that, like Goodman (2017), leverage exogenous variation in the amount of or quality of STEM coursework and measure long-term outcomes of students against a reasonable comparison group.

The basic logic behind increasing the absolute number of students studying STEM is that if more individuals acquire these skills, they will have better job prospects and drive economic growth via the increased introduction of new innovations. A recent paper by Bianchi (2016), however, identifies potentially important indirect effects at the university level that are important to consider. He studies the impact of a change in Italian law that allowed a large number of students to study STEM subjects in Italian universities for the first time during the 1960s. These new students came from technical high schools, which generally offered a narrower and more applied menu of coursework than academic-track high schools. Academic-track high school students were always able to choose STEM majors in universities and the reform did not constrain this flexibility.

He finds the introduction of these new students reduces academic performance of the incumbent academic track students, likely because of constraints on resources that increased faculty-to-student ratios and greater diversity in preparation across students. Further, Bianchi finds some high-potential students may have been induced to select non-STEM majors after the law was enacted. Finally, he finds some evidence that the law might have negatively affected lifetime earnings for STEM graduates overall. These results suggest policymakers considering expansions in STEM education opportunities should consider the possible direct and indirect impacts of such policies, what economists typically refer to as general equilibrium effects. These effects include not just the impact of a given policy on the absolute number of students who study STEM and their labor market outcomes, but also how these changes influence the economic returns to studying STEM (and other fields) for all students.

The link between STEM education and innovation

A new line of work also explores the link between STEM education and innovative activity later in life. Toivanen and Väänänen (2016) find that policy changes in Finland that led to greater opportunities to earn an engineering degree are related to the likelihood of patenting. Bianchi and Giorcelli (2017) investigate the relationship between STEM education and innovation, using the same 1960s-era reform in Italian universities discussed above. The authors find that, since the law was enacted, high-achieving students (based on high school grades) are actually less likely to generate new inventions. However, students with lower high school achievement are more likely to generate new inventions, compared to similar students who matriculated before the law.

Interestingly, the decrease in invention among high-achieving students was not necessarily from the highest potential prospective inventors. Using data on Italian inventors who patent in the United States (a proxy for quality), the authors conclude the decline in patenting among individuals who were high-achieving students was likely concentrated among those who would not have produced the very best inventions. The authors note the different occupational choices made by students after the change in law might explain these effects. This result indicates broad expansions of STEM education may not only influence the number of inventions produced, but also “who” produces them, by changing the composition of would-be inventors.

Another recent effort has taken a different approach to yield novel insights about the connection between STEM education and innovative activity later in the life. Bell et al. (2016) link federal tax returns and the U.S. patent data to investigate the link between human capital and innovation. They find that children of low-income parents (who are more likely to be in low-performing schools and have lower test scores) are far less likely to be inventors later in life, and differences that emerge in the early years of schooling can explain this disparity. The authors also find that children who grow up in a region where innovation in a specific technology class is prevalent are more likely to invent in that technology class as adults. This result suggests exposure to specific kinds of innovation in the early years might be important in determining how young people select their eventual fields of study and shape their decisions to become inventors. This logic could inform the design of many sorts of programs, for example, mentoring initiatives for low-income children.

The authors conclude that, particularly as it relates to math education, reducing the relationship between parental income and achievement could contribute significantly to innovative output in terms of patents by unlocking the potential of more individuals to develop inventions. Card and Giuliano (2014) provide related evidence that the strategic use of gifted and talented programs could be one mechanism to achieve this objective. Their study of gifted and talented initiatives suggests including disadvantaged students in these programs who do not meet the IQ cutoffs, but have scored well on state exams, may increase subsequent math and science performance for these students.

Skills beyond STEM and their role in innovation

Note that not all scholars take for granted that America's relative standing on STEM education indicators, such as math and science test scores, is a valuable signal of our nation's future innovative and entrepreneurial capability. For example, Bhide (2008) argues the large domestic market in the United States and the willingness of American consumers to experiment with new products is a central driver of innovation. Similarly, it is not clear the technical skills adequately measure the capacity for innovative entrepreneurship. Baumol (2005) observes that many successful entrepreneurs do not appear to have advanced technical training, and only a small fraction have created breakthrough innovations on their own. Interestingly, Baumol notes a possible tension between the kind of foundational technical skills that underlie incremental innovation and the sort of novel and creative approaches required to develop radical innovations. He posits that America's lead in many innovation indicators is not due to the sheer number of technically trained citizens (an area where we lag behind some peer nations) but is due in part to the flexibility of our education system and its attitude toward creativity.

Relatedly, Levine and Rubinstein (2016) find that individuals who start incorporated businesses in the United States are more educated and score higher on exams, but also engage in more illicit activities, such as drug use, than their peers. These results are consistent with the idea that creative and less structured tasks such as innovation and entrepreneurship may favor individuals who deviate from accepted norms. One implication of this study is that increasing STEM education at the expense of developing other skills could have an unintended impact on outcomes such as innovation and entrepreneurship.

Aside from math and science, other kinds of skills, including non-cognitive skills (Heckman 2006), could also be important in developing an innovative workforce. Cook et al.

(2014) find large effects on math scores from an intervention in Chicago schools whereby they provided both academic and non-academic remediation for students who were at risk of dropping out of school. The academic component consisted of a daily, one-hour math tutoring session with two students per instructor. The non-academic component was cognitive behavioral therapy to improve problem-solving, impulse control, and decision-making, delivered through 27 one-hour weekly sessions. The authors find that participation in this program raised math test scores by the equivalent of 15 percentile points within the distribution of national scores, and increased graduation rates by an estimated 14 percentage points.

Other, seemingly disparate, research in innovation and education suggest teaching “soft skills” such as social skills and teamwork in K-12 could play a role in increasing innovation and entrepreneurship. For example, consider Jones (2009), who documents the increase in teamwork in U.S. innovative activity and finds that inventor team size increased by 35% from 1975 to 1999. More recently, Deming (2015) finds that between 1980 and 2012, jobs with high social skill requirements increased by 10 percentage points as a share of the U.S. job market. If the results of these studies are considered in tandem, they imply that teamwork, which necessarily involves social skills to knit together larger groups of individuals, is crucial for developing new innovations. Although individuals can learn teamwork in different settings, including at home, through military service, and in employment, K-12 education could offer a particularly advantageous setting to develop these skills provided that we can develop evidence-based practices.

Interestingly, despite the significant attention from policymakers on STEM skills and, to a lesser extent, non-cognitive skills, to my knowledge, little empirical work has documented the mechanisms by which increasing the skill level of a population can enhance the quality and quantity of innovation. Although more educated populations might produce more innovations, a relatively small share of citizens are directly involved in innovation in advanced economies. Whether raising the math and science skills of the average American student would have a significant impact on this metric is unclear, based on the current literature. Nor do we have any experimental evidence that I am aware of that specific retraining programs lead to increases in the quality and quantity of innovation. These topics appear ripe for future research.

Conclusion: An Emerging Innovation Agenda for Education?

Despite a large amount of attention from policymakers and the media about the potential for technological innovation to yield dramatic improvements in our K-12 education system, we have yet to see significant gains in outcomes or reductions in cost. Relatedly, although it is intuitive to believe that a skilled workforce, particularly in STEM subjects, will create more innovations, scant direct evidence for this conjecture exists. These gaps present a tremendous opportunity for new research to generate actionable policy insights.

Two broad themes emerge from this paper. First, prior work has argued that more rigorous and rapid evaluations of educational hardware and software can spur wider adoption of productivity-enhancing technological tools in the classroom (Chatterji and Jones 2012). The proposed mechanism of action is that institutions that allow demonstration of “what works” will both provide stronger incentives to would-be innovators and facilitate broader scaling of useful technologies, particularly where demand is already aggregated. The emerging literature on this topic suggests the kind of technology being tested is a first-order concern (Muralidharan, Singh and Ganimian 2016). Some initial evidence suggests “personalized” learning software is particularly promising in terms of raising student outcomes. But to properly deploy these tools, we first require a deeper understanding of how students learn. Moreover, an interesting complementary path will be to explore how organizational and pedagogical innovations facilitate student learning. Finally, other kinds of outcomes, such as engagement and general technological fluency, should be assessed in conjunction with traditional student performance measures.

These open questions underscore the noticeably low levels of research and development in education. In comparison to other national priorities, we have yet to define a coherent R&D agenda nor have comparable resources been devoted to it. This marked disparity indicates that a promising agenda would entail understanding why private and public organizations have not invested large sums in education R&D to date, identifying levers that might be used to encourage increased investment and articulating a set of research questions that should be prioritized.

For example, it would important to consider whether new investments in education R&D should be managed from the U.S. Department of Education, other research agencies like the National Science Foundation, or a new entity entirely. Separately it would be interesting to document what types of research private sector firms and school districts are already conducting to better understand the prospective direction of innovation. Finally, developing the specific research questions to be answered would ideally be done by an interdisciplinary set of scholars and practitioners, given that research on education spans several academic disciplines and contexts.

The second key theme of this paper is to highlight the need for new research that links educational interventions to longer-term outcomes, such as patenting and starting firms. The insights we do have in this domain (e.g., Bell et al. (2016) are often dependent on access to sensitive government databases. To establish reliable evidence on how K-12 education is connected to an innovative and entrepreneurial workforce, we will need more research utilizing these kinds of data and the creation of new datasets.

The workforce of tomorrow is in school today. Understanding how the hardware and content we provide them shapes their acquisition of knowledge and long-term outcomes is a first-order economic policy issue. A tremendous untapped opportunity at the intersection of innovation and education has the potential to broaden access, increase quality, and lower costs. One promising path forward could be sustained research collaborations between government, business, academia, and K-12 schools to generate rigorous evidence on these important questions.

References

Aghion, P., U. Akcigit, O. Toivanen and A. Vaananen (2015). "Living the American Dream in Finland: The Social Mobility of Innovators", unpublished manuscript.

Angrist, J. and V. Lavy (2002). "New evidence on classroom computers and pupil learning." The Economic Journal **112**(482): 735-765.

Angrist, J. D., P. A. Pathak and C. R. Walters (2013). "Explaining charter school effectiveness." American Economic Journal: Applied Economics **5**(4): 1-27.

Augustine, N. R., C. Barrett, G. Cassell, N. Grasmick, C. Holliday and S. Jackson (2010). "Rising above the gathering storm, revisited: Rapidly approaching category 5." Washington, DC: National Academy of Sciences, National Academy of Engineering, Institute of Medicine.

Banerjee, A. V., S. Cole, E. Duflo and L. Linden (2007). "Remedying education: Evidence from two randomized experiments in India." The Quarterly Journal of Economics **122**(3): 1235-1264.

Barrow, L., L. Markman and C. E. Rouse (2009). "Technology's edge: The educational benefits of computer-aided instruction." American Economic Journal: Economic Policy **1**(1): 52-74.

Baumol, W. J. (2005). "Education for innovation: Entrepreneurial breakthroughs versus corporate incremental improvements." Innovation Policy and the Economy **5**: 33-56.

Baumol, W. J. (2012). The cost disease: Why computers get cheaper and health care doesn't, Yale university press.

Baumol, W. J. and W. G. Bowen (1966). Performing Arts--the Economic Dilemma: A Study of Problems Common to Theatre, Opera, Music and Dance, MIT Press.

Bell, A., R. Chetty, X. Jaravel, N. Petkova and J. Van Reenen (2016). "The lifecycle of inventors." unpublished manuscript.

Bettinger, E. (2010). To be or not to be: Major choices in budding scientists. American universities in a global market, University of Chicago Press**:** 69-98.

Bhide, A. (2008). The venturesome economy: How innovation sustains prosperity in a more connected world. . Princeton, N.J: Princeton University Press.

Bianchi, N. (2016). "The Indirect Effects of Educational Expansions: Evidence from a Large Enrollment Increase in STEM Majors". unpublished Manuscript.

Bianchi, N. and M. Giorcelli (2017). "Scientific Education and Innovation: From Technical Diplomas to University STEM Degrees". unpublished manuscript.

Bloom, N., R. Lemos, R. Sadun and J. Van Reenen (2015). "Does management matter in schools?" The Economic Journal **125**(584): 647-674.

Bloom, N., R. Sadun and J. Van Reenen (2012). "Americans do IT better: US multinationals and the productivity miracle." The American Economic Review **102**(1): 167-201.

Bulman, G. and R. W. Fairlie (2016). "Technology and education: Computers, software, and the internet", NBER Working Paper No. 22237.

Card, D. and L. Giuliano (2014). "Does gifted education work? For which students?", NBER Working Paper No. 20453.

Chabrier, J., S. Cohodes and P. Oreopoulos (2016). "What Can We Learn from Charter School Lotteries?" The Journal of Economic Perspectives **30**(3): 57-84.

Chatterji, A. and B. Jones (2012). "Harnessing Technology to Improve K-12 Education. ." The Hamilton Project, Discussion Paper 2012-05.

Chatterji, A. and B. Jones (2016). "Learning What Works in Educational Technology with a Case Study of EDUSTAR." The Hamilton Project, Policy Memo 2016-01.

Cheung, A. C. and R. E. Slavin (2013). "The effectiveness of educational technology applications for enhancing mathematics achievement in K-12 classrooms: A meta-analysis." Educational research review **9**: 88-113.

Cook, P. J., K. Dodge, G. Farkas, R. G. Fryer Jr, J. Guryan, J. Ludwig, S. Mayer, H. Pollack and L. Steinberg (2014). "The (surprising) efficacy of academic and behavioral intervention with disadvantaged youth: results from a randomized experiment in Chicago", NBER Working Paper No. 19862.

Cuban, L., H. Kirkpatrick and C. Peck (2001). "High access and low use of technologies in high school classrooms: Explaining an apparent paradox." American Educational Research Journal **38**(4): 813-834.

Cutler, D. M. (2011). "Where are the health care entrepreneurs? The failure of organizational innovation in health care." Innovation Policy and the Economy **11**(1): 1-28.

Deming, D. J. (2015). "The growing importance of social skills in the labor market.", NBER Working Paper No. 21473.

Dobbie, W. and R. G. Fryer Jr (2013). "Getting beneath the veil of effective schools: Evidence from New York City." American Economic Journal: Applied Economics **5**(4): 28-60.

Fairlie, R. W., D. O. Beltran and K. K. Das (2010). "Home computers and educational outcomes: evidence from the NLSY97 and CPS." Economic Inquiry **48**(3): 771-792.

Fryer Jr, R. G. (2017). "Management and Student Achievement: Evidence from a Randomized Field Experiment", NBER Working Paper No. 23437.

Goodman, J. (2017). "The Labor of Division: Returns to Compulsory High School Math Coursework", NBER Working Paper No. 23063.

Goolsbee, A. and J. Guryan (2006). "The impact of Internet subsidies in public schools." The Review of Economics and Statistics **88**(2): 336-347.

Heckman, J. J. (2006). "Skill formation and the economics of investing in disadvantaged children." Science **312**(5782): 1900-1902.

Hulleman, C. S. and J. M. Harackiewicz (2009). "Promoting interest and performance in high school science classes." Science **326**(5958): 1410-1412.

Hulten, C. and V. Ramey (2015). "Introduction: Skills, Education, and US Economic Growth: Are US Workers Being Adequately Prepared for the 21st Century World of Work?". Education, Skills, and Technical Change: Implications for Future US GDP Growth, University of Chicago Press.

Jaffe, A. B. and J. Lerner (2011). Innovation and its discontents: How our broken patent system is endangering innovation and progress, and what to do about it, Princeton University Press.

Jones, B. F. (2009). "The burden of knowledge and the “death of the renaissance man”: Is innovation getting harder?" The Review of Economic Studies **76**(1): 283-317.

Kerr, W. R. and W. F. Lincoln (2010). "The supply side of innovation: H-1B visa reforms and US ethnic invention." Journal of Labor Economics **28**(3): 473-508.

Ladd, H. F. (2002). "School vouchers: A critical view." The Journal of Economic Perspectives **16**(4): 3-24.

Lander, E. S. and S. J. Gates (2010). "Prepare and inspire." Science **330**(6001): 151-151.

Levine, R. and Y. Rubinstein (2016). "Smart and Illicit: Who Becomes an Entrepreneur and Do they earn more?" The Quarterly Journal of Economics: qjw044.

Machin, S., S. McNally and O. Silva (2007). "New technology in schools: Is there a payoff?" The Economic Journal **117**(522): 1145-1167.

Muralidharan, K., A. Singh and A. J. Ganimian (2016). Disrupting Education? Experimental Evidence on Technology-Aided Instruction in India, NBER Working Paper No. 22923.

Pashler, H., M. McDaniel, D. Rohrer and R. Bjork (2008). "Learning styles concepts and evidence." Psychological Science in the Public Interest **9**(3): 105-119.

Ragosta, M. (1982). Computer-assisted Instruction and Compensatory Education: The ETSI LAUSD Study Washington, DC, National Institute of Education.

Romer, P. M. (2000). "Should the government subsidize supply or demand in the market for scientists and engineers?" Innovation policy and the economy **1**: 221-252.

Rouse, C. E. and A. B. Krueger (2004). "Putting computerized instruction to the test: a randomized evaluation of a “scientifically based” reading program." Economics of Education Review **23**(4): 323-338.

Saxenian, A. (2007). The new argonauts: Regional advantage in a global economy. Cambridge,MA, Harvard University Press.

Shu, P. (2016). Innovating in Science and Engineering or'Cashing In'on Wall Street? Evidence on Elite STEM Talent. unpublished manuscript.

Stephan, P. E., A. J. Sumell, G. C. Black and J. D. Adams (2004). "Doctoral education and economic development: The flow of new Ph. Ds to industry." Economic Development Quarterly **18**(2): 151-167.

Stern, S. (2004). "Do scientists pay to be scientists?" Management science **50**(6): 835-853.

Stiroh, K. J. (2002). "Information technology and the US productivity revival: A review of the evidence." Business Economics **37**(1): 30.

Toivanen, O. and L. Väänänen (2016). "Education and invention." Review of Economics and Statistics **98**(2): 382-396.

Wenglinsky, H. (1998). "Does it compute? The relationship between educational technology and student achievement in mathematics". Princeton, NJ, Educational Testing Service.

Woodworth, J. L., M. Raymond, K. Chirbas, M. Gonzalez, Y. Negassi, W. Snow and C. Van Donge (2015). "Online Charter School Study 2015". Stanford, CA: Center for Research on Education Outcomes, Stanford University.

Figure 1: R&D Spending by Industry

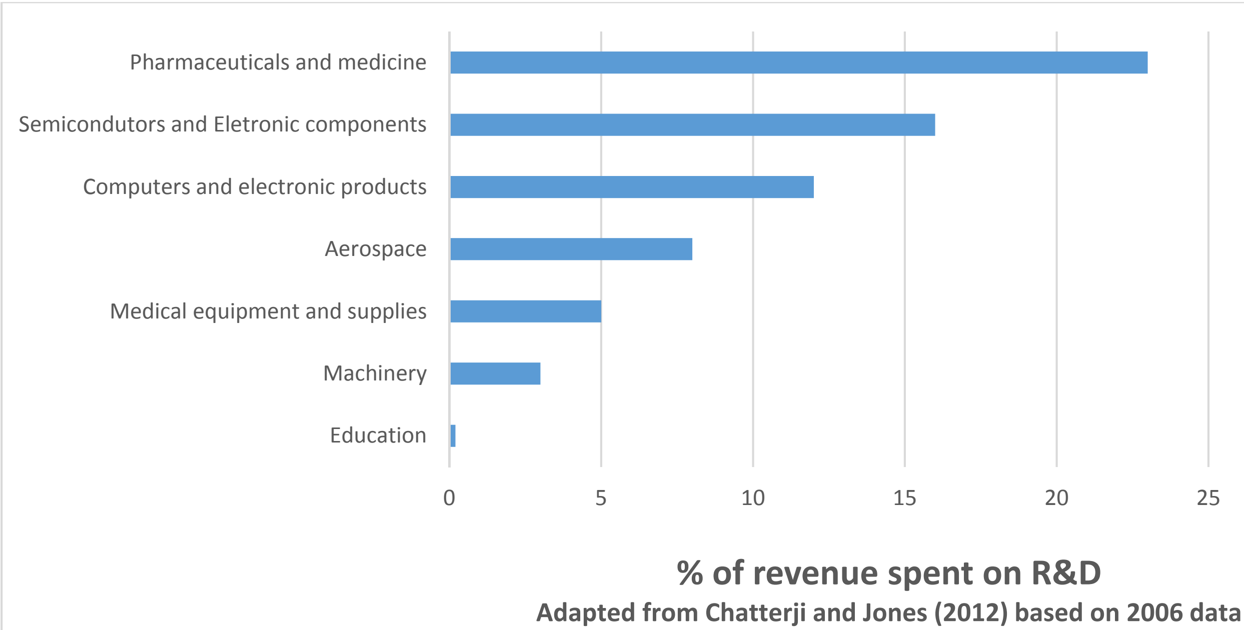
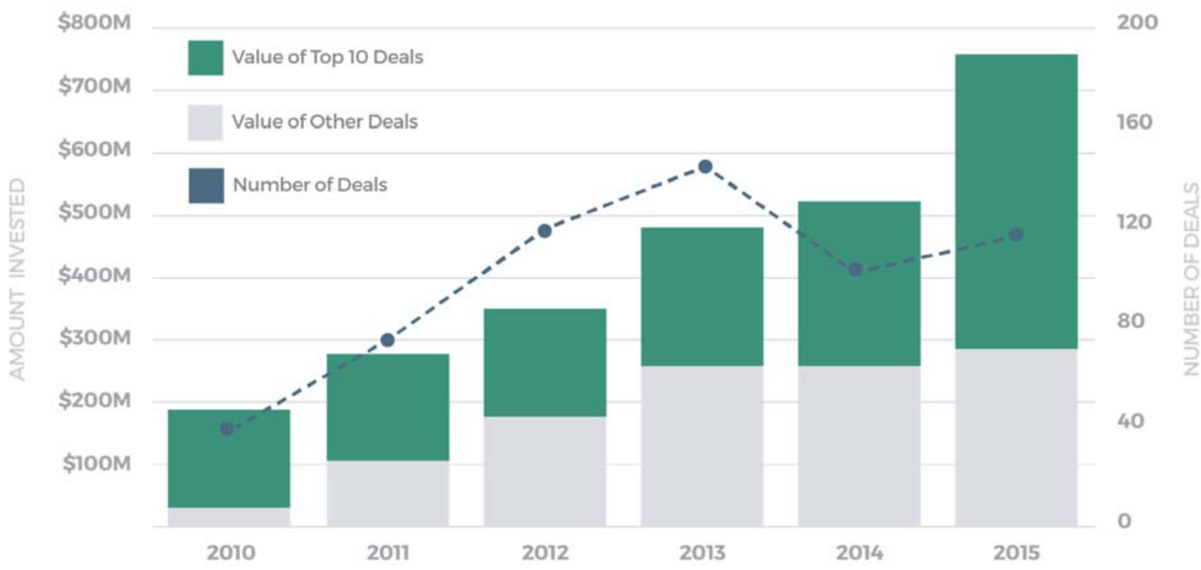
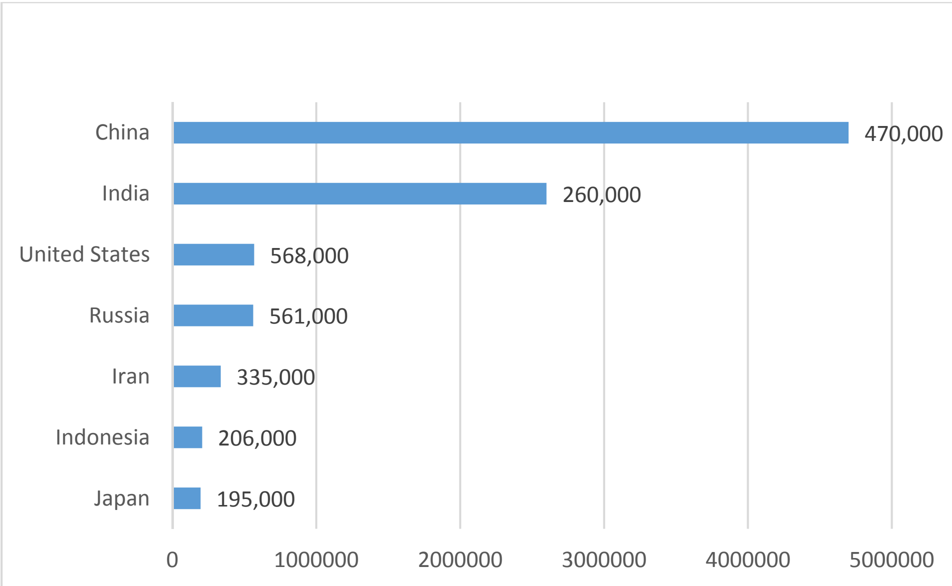


Figure 2: Investments in Education Technology Companies (2010-2015)



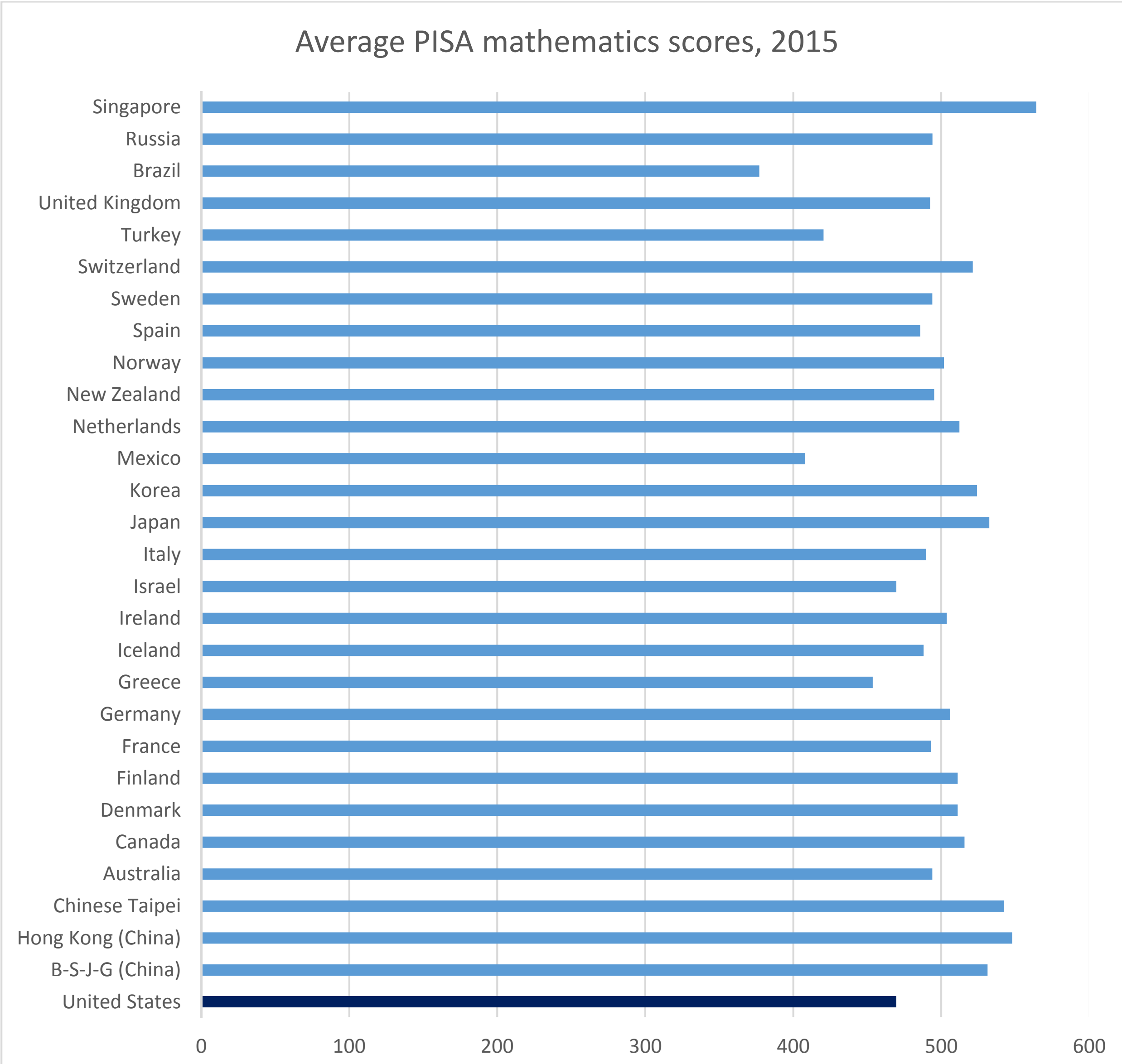
Source: EdSurge (https://www.edsurge.com/research/special-reports/state-of-edtech-2016/funding#investments)

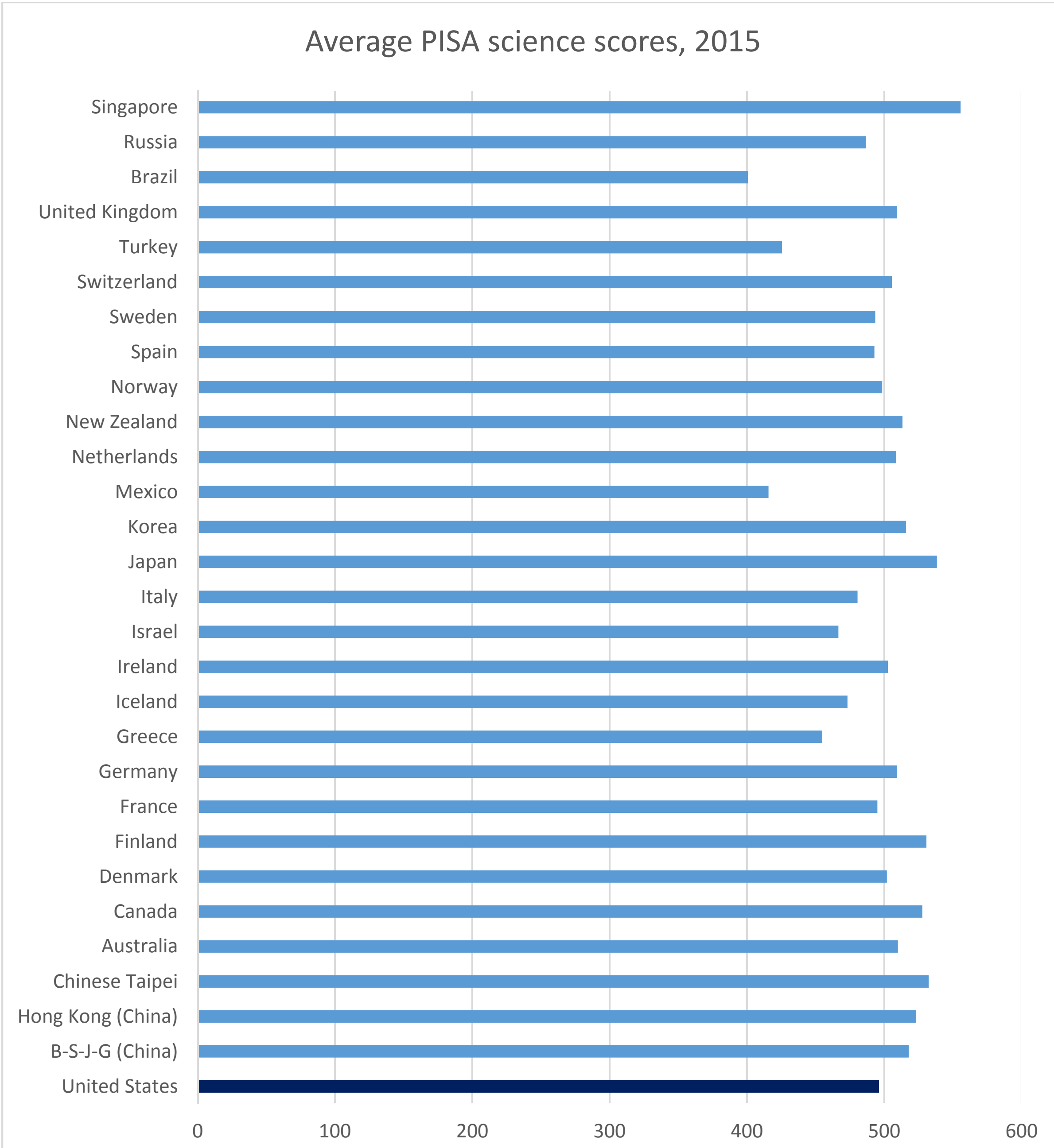
Figure 3: STEM Graduates by Selected Countries, 2016



Source: World Economic Forum Data

Figure 4: International Math and Science Scores for High School Students




Average PISA science scores, 2015
Singapore
Russia
Brazil
United Kingdom
Turkey
Switzerland
Sweden
Spain
Norway
New Zealand
Netherlands
Mexico
Korea
Japan
Italy
Israel
Ireland
Iceland
Greece
Germany
France
Finland
Denmark
Canada
Australia
Chinese Taipei
Hong Kong (China)
B-S-J-G (China)
United States
0
100
200
300
400
500
600