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Why the Current Education Reform Strategy Won't Work

To improve innovation and boost the economy, the nation needs a fundamentally new approach to education in science, technology, engineering, and mathematics.

For over half a century, innovations based on science and engineering have powered the U.S. economy, creating good jobs, a high standard of living, and international economic leadership. Yet, as the National Science Board documented in *Science and Engineering Indicators: 2012*, the nation's global share of industries focused on science, technology, engineering, and mathematics—the group widely known as STEM—is in decline. Moreover, the nation is not able to produce enough STEM workers domestically in key fields. Although increasing the quantity and quality of U.S. graduates in STEM fields will not turn around declining U.S. innovation-based competitiveness, it is an important component of a national innovation strategy.

Although a few policy experts have disputed this framing—as Harold Salzman and B. Lindsay Lowell did in their 2007 book *Into the Eye of the Storm: Assessing the Evidence on Science and Engineering Education*—most have embraced it. In fact, the past quarter-century has seen a widespread consensus that the United States needs to do a better job at promoting and supporting STEM education. Numerous task forces, commissions, and study groups have produced an array of reports sounding the same alarm, identifying the same problems, and calling for largely the same solutions.

Yet the problems remain. The number of bachelor's of science degrees in engineering awarded over the past 15 years has barely grown, and master's degrees in STEM have increased at about half the rate of non-STEM master's degrees. Also, almost half of doctoral STEM degrees are now awarded to foreign nationals. Many observers attribute the failure to reverse these trends to a lack of political will. If only elected leaders would take the problem seriously and devote significant resources, the thinking goes, the nation could solve the problem. But the nation has, in fact, taken action. Congress has passed numerous bills, and several presidential administrations, including the Obama administration, have established a variety of STEM initiatives.

It is therefore time to consider whether the problem is not a lack of political will but rather a lack of the right con-

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ceptual framework. The dominant framework, and the one that informs virtually all policy deliberations on STEM, is based on what can be termed the "Some STEM for All" approach. In this view, STEM is so important for individual opportunity that the nation must make sure that along every step of the way, but particularly in elementary and middle school, all students get as much high-quality STEM education as possible. This solution would involve raising the quality of STEM teachers from kindergarten through 12th grade, imposing rigorous STEM standards, improving curriculum, and boosting awareness among students of the attractiveness of STEM careers. Unfortunately, even if all of these steps could be funded—which is not the case, given fiscal realities—they would not solve the problem.

Instead, it is time to introduce a new framework based on an "All STEM for Some" approach, where the purpose of driving STEM education is not principally to create economic opportunity for individuals but to provide the "fuel" needed to power a science- and technology-driven U.S. economy. The framework will require working actively to recruit those students who are most interested in, and capable of doing well in, STEM and providing them with the kind of educational experience they need to make it all the way through the educational pipeline and come out ready, willing, and able to contribute to growing the U.S. innovation economy.

In short, if the nation is to more effectively address the STEM challenge, fresh thinking and fresh approaches are needed. This effort will involve facing down six myths that have emerged about the prevailing Some STEM for All framework, and then adopting two particular policy solutions to set the nation on a better path.

Alternate STEM reality

The first myth is that in a globalized, technology-driven world, all students needs to learn STEM. In this view—so widely held that it is virtually never questioned—the economy will be so innovation-based that everyone, even those who will never become Ph.D. scientists, will need to learn as much STEM as possible. The reality is quite different. Only about 5% of jobs are STEM jobs, and that share is not expected to grow significantly. This is one of the findings that my colleague Merrilea Mayo and I reported in *Refueling the U.S. Innovation Economy: Fresh Approaches to Science, Technology, Engineering, and Mathematics Education*, issued in December 2010 by the Information Technology and Innovation Foundation. Very few workers actually need advanced STEM education, and surveys of employers reinforce that. One survey noted in our report found that although 70% of employers rated oral communication skills as very important for high-school graduates, only 9% rated science skills as very important. The rate was higher for four-year college graduates, but still only 33% of employers rated science skills as very important, compared with 90% who rated writing skills as very important.

Saying that the nation should pour resources into K-12 because everyone needs to know STEM is akin to saying that because music is important to society, every K-12 student should have access to a Steinway piano and a Juilliard-trained music teacher. In fact, because very few students become professional musicians, doing this would be a waste of societal resources. It would be far better to find students interested in music and give them the focused educational opportunities they need. STEM is no different.

The second myth is that focusing on K-12 will ensure that enough students graduate from college with STEM degrees. The Some STEM for All view holds that the best way to increase college STEM graduates is to boost STEM skills in the early years, as argued by many observers and reports, including the National Academies' 2007 report *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*. In this view, it is too late to focus on college, or even high school, for promoting STEM.

This can be described as the "leaky pipeline" model, in which kids enter the educational flow but drop out through leaks along the way. Norman R. Augustine, who chaired the committee that produced *Rising Above the Gathering Storm*, described this leakage in another 2007 Academies' report, *Is America Falling Off the Flat Earth?* "As one might suspect," he wrote, "there is a great deal of leakage along that extended educational highway. To begin with, about one-third of U.S. eighth-graders do not receive a high school diploma. And of those who do, about 40 percent do not go on to college. About half who do begin college do not receive a bachelor's degree. Of those who do receive such a degree, two-thirds will not be in science or engineering. And of those who are U.S. citizens and do receive degrees in either science or engineering, only about 1 in 10 will become candidates for a doctoral degree in those fields. And over half the doctoral candidates drop out before being awarded a Ph.D."

If the goal is to have every high-school graduate be able and ready to major in a STEM field in college, then ensuring that the pipeline is completely full by the end of the eighth grade is critical. That is why the *Gathering Storm* report so strongly declared that "the U.S. system of public education must lay the foundation for developing a workforce that is literate in mathematics and science." As the report continued, "The point is that it takes a lot of third-graders to produce one contributing research scientist or engineer and a very long time to do it." In other words, if everyone has an equal probability of taking the next step to become STEM-educated, then the best way to get more at the end of the pipeline is to put a lot of students in at the beginning.

There are two problems with this logic, however. First, not everyone has an equal probability of getting a graduate STEM degree. At the risk of violating political correctness, the fact is that being a scientist or engineer requires above-average intelligence. But the nation is not a huge Lake Wobegon, the fictional community where all the children are above average. Moreover, it is not just intelligence that determines a student's likelihood to go into STEM; it is also personality. There is a long tradition of research exploring the link between personality characteristics and choice of occupation, including STEM occupations. A new study, reported by Scott Andrew Shane in his 2010 book *Born Entrepreneurs, Born Leaders: How Your Genes Affect Your Work Life*, has found that the choice of careers in physical science and engineering was about 70% more influenced by a person's genetic makeup than were choices in such areas as finance and sales. Assuming that exposing every student to a lot of high-quality STEM education will make them want and be able to become a scientist or engineer is simply wishful thinking, just as it would be to assume that every student exposed to high-quality music education and a requirement to take four years of music in high school will want and be able to become a professional musician.

The second problem, as noted above, is that the nation does not need everyone to gain a STEM degree. In fact, the current pipeline produces enough high-school students able to get the needed number of STEM college degrees. But society currently does a poor job in high school and college of helping those students get all the way to a STEM degree. To use the pipeline analogy, replacing a malfunctioning valve is likely to be a more effective, and much cheaper, strategy than increasing the size of a five-mile-long pipe.

The third myth is that more students would become STEM graduates if they knew how important or "cool" STEM is. In other words, solving the pipeline problem is a marketing challenge. The National Science Board's (NSB's) *National Action Plan 2007* reflected this view when it called for the National Science Foundation (NSF) to "continue to develop and fund programs that increase public appreciation for and understanding of STEM."

This view, however, ignores the fact that U.S. culture is already enthusiastic about science. For example, one survey reported by the NSB in *Science and Engineering Indicators 2010* found that 80% of respondents stated that they were "very" or "moderately" interested in new scientific discoveries. Most people hold scientists in very high regard, ranking them second (behind military leaders) in terms of public confidence. Overall, the public's enthusiasm for science rivals (if not exceeds) that of people in China and South Korea, while far outstripping that of Europeans, Russians, and the Japanese.

But that does not deter the "make science cool" effort, even though it has not been shown to work. In 1994, a survey by the National Action Council for Minorities in Engineering (NACME) found that only 6% of disadvantaged minorities were graduating from high school with the math needed for an engineering or related degree. The survey also found that students did not recognize the importance of math as a foundation for later achievement. To reverse these trends, NACME launched the public service campaign Math is Power, which included targeted television advertisements emphasizing the importance of math to jobs with higher wages. Four years later, NACME found in a follow-up survey that "Half of all students surveyed are aware of the campaign, with a majority of them familiar with at least one of its key messages and that overall students had more favorable attitudes towards math." However, its impact on behavior was negligible. In fact, students were "less likely to think that the decision to take math and science classes is an important one. They are also less likely to view math as important for their careers than they were six years ago." The results suggest that using mass media to reshape student attitudes may in fact work, but the changed attitudes do not necessarily translate to changed behaviors.

Different views of teachers

The fourth myth is that paying STEM teachers more is key to improving STEM education. The NSB made this argument, for example, in a 2007 report called *Boosting the Supply and Effectiveness of Washington's STEM Teachers*, which resulted from a study conducted through its New Teacher Project. In a similar vein, the Education for Innovation Initiative, a coalition of 15 of the nation's most prominent business organizations, recommended that math and science teachers be placed on higher pay scales, asserting that it will "foster higher student achievement."

But pay raises are not likely to solve the problem. A study by the Raytheon Company found that because school administrators lack the metrics to differentiate between more- and less-effective teacher candidates, the resulting blindness in hiring largely negates the benefit of having a pay-induced larger candidate pool. In a 2007 report on the study, *Modeling Student Interest in Science, Technology, Engineering, and Mathematics*, the company said "the data show that increasing teacher pay does not result in better teachers. The model showed that an increase in teacher pay increases the candidate pool. This would improve teacher quality if school administrators hired the more capable new teachers from the larger pool of candidates, but there is an absence of data to support a conclusion that this will happen." Moreover, the company suggested that over the long term, industry salaries will simply rise, thereby negating the incentive built into the original salary increase.

Educational researchers have reported similar findings. For example, Eric A. Hanushek and Steven G. Rivkin studied the movement of teachers within the Texas Public School System. In a report in the spring 2007 issue of *Future of Children*, they concluded: "With few exceptions, advocates of across-the-board salary increases pay too little heed to teachers' classroom performance and to administrators' personnel decisions."

Finally, this is an extremely expensive strategy. Assuming that an additional $10,000 salary premium would be needed per public school teacher, the United States would have to invest about $2.7 billion annually to achieve what is at best a questionable impact, according to a study by Sylvia A. Allegreto, Sean P. Corcoran, and Lawrence R. Mishel published in the *Digest of Education Statistics: 2009*.

The fifth myth is that STEM teachers with a STEM degree are the answer. If more money cannot buy higher STEM teacher quality, then surely requiring teachers to have STEM degrees can. The *Gathering Storm* report underscored technical expertise in the classroom, arguing: "We need to recruit, educate, and retain excellent K-12 teachers who fundamentally understand biology, chemistry, physics, engineering, and mathematics. The critical lack of technically trained people in the United States can be traced directly to poor K-12 mathematics and science instruction."

However, research linking subject-matter expertise and teacher quality suggests a weak correlation at best, and no correlation at worst. One analysis of the Florida public school system, conducted by Douglas N. Harris and Tim R. Sass, found no significant correlation between advanced degrees and teacher effectiveness in the subjects of math and reading. In a 2007 report on the study, published by the National Center for Analysis of Longitudinal Data in Education Research, the researchers concluded: "Like other recent work, we find generally positive, but mixed, evidence on the effects of experience and little or no evidence of the efficacy of advanced degrees for teachers . . . Only in the case of middle school math do we find that obtaining an advanced degree enhances the ability of a teacher to promote student achievement. For all other grade/subject combinations the correlation between advanced degrees and student achievement is negative or insignificant."

Another study of 3,784 12th-grade math students and 2,524 12th-grade science students found that only about 8% of the standard deviation on student math test scores could be attributed to the teacher's having a master's degree in math, with results for bachelor's degrees in math being similar. The researchers, Dan D. Goldhaber and Dominic J. Brewer, published the results of the study in the June 20, 2000, issue of *Educational Evaluation and Policy Analysis*. Teacher training in science showed far less of an effect and actually a small negative effect for teachers with bachelor's degrees in science. Overall, as Goldhaber concluded in another study reported in an article titled "The Mystery of Good Teaching," published in 2002 in *EducationNext 2*, what matters in science and math education is such qualities as enthusiasm, skill in relaying knowledge, intelligence, and the ability to relate to children.

Solutions that call for higher education levels of STEM teachers underestimate the cost-to-benefit ratio of such programs. Data from the 2002 National Educational Longitudinal Study shows that 43.5% of K-12 math teachers have bachelors' degrees or higher in math, and an additional 16% have a minor or second degree in math at the bachelor's level. Bringing the remaining math teachers without at least a bachelor's degree in math up to this level would require considerable money, all for what amounts to, at most, 8% of a standard deviation's improvement in student performance (and much less for science), according to estimates by Goldhaber, who is director of the Center for Education and Data Research at the University of Washington Bothell.

The sixth myth is that requiring more STEM courses and more standardized courses is the key. If the goal is to expand the number of K-12 students in the STEM talent pipeline, then it seems logical to require students to learn the same STEM material and more of it. In this spirit, advocates of Some STEM for All almost universally argue for standardizing science curricula and expanding STEM requirements. As the NSB's *National Action Plan* stated: "STEM content standards and the sequence in which content is taught vary greatly among school systems, as do the expectations for and indicators of success. Because states have no consensus on what key concepts students should master and should be included in the curriculum at a certain grade level or within a specific content area, textbooks often cover too many topics at too superficial a level, rather than focus on a few key topics in-depth."

The most dramatic step toward a standardized curriculum is the Common Core State Standards Curriculum, which

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seeks to create common K-12 content standards in mathematics and English language arts. As part of this push, there are also calls for more STEM course requirements. The Texas legislature, for example, recently added a fourth year of science and math to its already long list of subjects required for graduation.

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There are at least two problems with the core movement. The first is that if a course is not part of the core requirements, it is essentially relegated to irrelevance (e.g., it is an elective). This is why courses in computer science, a field that employs more than 70% of all STEM workers, are largely ignored in high schools. Only 10 states allow computer science courses, if they even exist, to count as a core mathematics or science requirement. This is one reason why in the past 15 years, enrollment in the Computer Science AB Advanced Placement (AP) test grew by just 12% while enrollment in the Music Theory AP test grew by 362% and why three times as many students in 2008 took the Art History AP test as the Computer Science AB AP test. What does it say about the success of the Some STEM for All movement that after at least a decade of effort, so few students were taking the Computer Science AB AP test that the College Board no longer offers it? And for the record, computer science is vastly more valuable to society than art history or music theory.

But the deeper and more troubling aspect of the core movement is that it assumes that high-school students are all the same, that they have no unique interests, and that for their own good they all must be forced to learn the same thing. But students are not all the same. Some have a passion for English and writing. Some for mechanics and engineering. Still others may be budding lawyers and want to immerse themselves in U.S. history, rhetoric, and logic. But for the school system, student interests are largely irrelevant. As education reform experts Ted Kolderie and Tim McDonald have written in *How Information Technology Can Enable 21st Century Schools*: "Conventional school is like a school bus rolling along the highway, with the teacher standing at the front and pointing out interesting and important sights but telling the passengers that, no, we cannot let you get off to explore what's down that side road. As a result students who want to pursue their interests and passions must do so on their own time and energies, if after completing all the required homework, they have any left."

This goes a long way toward explaining why the national High School Survey of Student Engagement found in its 2009 study that two-thirds of high-school kids are bored every day in class. In short, the Some STEM for All approach ignores the central enabler of effective STEM education:

motivated and interested students. The challenge is in designing an educational system, particularly in grades 9 through 12, that respects the desires of students to be active learners.

Fewer but better

The Some STEM For All paradigm certainly sounds logical to many people, and that goes a long way toward explaining its widespread following. But given the resources required to implement the recommendations that flow from the framework, it is extremely unlikely that the United States will implement many of them. And even if it did, this would not solve the problem.

The All STEM for Some framework provides a better analysis of the problems and recommendations that are more likely to be implemented and effective. Its goal is to ensure that an adequate, even if small, share of U.S. students become high-quality, entrepreneurial, and engaged STEM graduates. What the economy really needs is a modest increase in the number of STEM college graduates who have a real increase in their STEM skills—that is, graduates with stronger fundamental skills, deeper knowledge of at least one discipline, and roots in at least two disciplines. It needs people who not only can generate new ideas but also have the skill set to move their ideas into products, acting as entrepreneurs either inside or outside corporate walls.

To help in reaping the advantages of the new approach, one key step will be to devote relatively more effort to the high-school and college levels, but in new ways. Perhaps the single most important step at the high-school level is to establish more STEM high schools so that the subset of students especially interested in STEM and most capable of becoming STEM workers can get the educational experience they need. STEM high schools are publicly funded schools that offer more extensive, in-depth math and science coursework. They also draw students from a larger geographic area than a traditional local public school. Instead of offering just chemistry, biology, and physics, these schools can offer Biomedical Physics, Immunology, Microbiology, Multivariable Calculus Number Theory, Math Modeling, Computer Programming III, and Web Application Development, to name a few classes available at the Arkansas School for Mathematics, Sciences, and the Arts.

Despite their effectiveness, there are only approximately 100 math and science high schools nationwide, enrolling around 47,000 students. To remedy this situation, the President's Council of Advisors on Science and Technology has called for the creation of 200 more math and science high schools, urging the Department of Education and NSF to develop a joint plan for accomplishing this goal. (This proposal came about, in part, from recommendations of the Information Technology and Innovation Foundation.) Congress should jump-start this effort by allocating $200 million a year for 10 years to the Department of Education, to be supplemented by states and local school districts and industry. The overall goal should be to increase by a factor of five the number of STEM high schools and increase enrollment to around 235,000 students by 2015. If Congress does not want to allocate new funds, it could instead require that all states, as a condition of receiving federal education aid, have at least one STEM high school for every 27,000 K-12 students.

But even as improving high schools will be important, colleges represent the real low-hanging fruit. Fifty-nine percent of students who enter college intending to major in STEM, most presumably with at least some of the skills to do well, do not obtain a STEM degree of some kind (certificate, associate's, bachelor's) after six years, according to data compiled by Xianglei Chen for the National Center for Education Statistics. They switch out to another major or drop out of college. For those students who switch out, it is not the quality of the student that is at issue, according to research reported by Elaine Seymour and Nancy M. Hewitt in their 1997 book *Talking About Leaving: Why Undergraduates Leave the Sciences*. The switchouts are equally as or more talented and prepared than the stayers. If the nation can reduce the number of STEM switchouts and dropouts by half, it could essentially solve the STEM worker shortage problem.

It is no mystery why switchouts and dropouts are so high. Seymour and Hewitt found that poor teaching was cited as a concern among 90% of students who switch out of STEM majors and 98% of students who switch out of engineering. All too often, teachers (and administrators) in disciplines such as engineering and physics go out of their way to make the first year difficult, boring, and painful. One way they do this is by saving the interesting and/or experiential classes until later grades. Another is by grading tougher. A College Board survey of 21 selective universities found that 85% of students in English classes received an A or a B, while the rate was just 57% for students in math classes, as reported by Paul M. Romer in a paper, "Should the Government Subsidize Supply or Demand in the Market for Scientists and Engineers?", published in 2000 by the National Bureau of Economic Research. This did not come about because the smart kids are in English. It would probably be possible to eliminate discouragingly low grades in STEM, and boost student retention, by having all colleges and universities mandate a "median grade" across all classes, majors, or colleges.

As Romer noted in his study of STEM education, "The picture that emerges from this evidence is one dominated by undergraduate institutions that are a critical bottleneck in the training of scientists and engineers." This bottleneck problem is much more easily and cheaply fixed than giving every K-12 STEM teacher a salary increase. One place to start is to understand that some colleges, such as Olin College outside of Boston, have figured out how to do this right. Olin, an engineering-only school, has no departments (or faculty tenure), and the student experience is exceptionally rich and integrated.

The key is giving universities and colleges an incentive to change. For now, the reality is that the status quo imposes no penalties: Students who switch out of STEM still pay tuition and still take classes that employ faculty. State schools still get their full-time equivalent-based money from state governments. From the perspective of the leadership of the college or university, students who switch out have no negative impact on the institution. From the perspective of humanities and social science departments, switchouts help ensure that there are enough students to enroll in their classes. And science department size is already calibrated to a standard level of switchouts; if they really put in place practices to reduce it, the college or university leadership would probably not cut resources and faculty in the humanities and social sciences in order to expand resources and faculty in the hard sciences. Even students who drop out entirely are also replaced by students transferring in or by those in the upcoming class.

With so many competing issues requiring time, attention, and resources, the only way to make STEM retention rise to the top of the academic "to-do" list is to supply external incentives that provide hard backing to good intentions. This can be done, on the one hand, by establishing a set of carrots or sticks (or both) to encourage today's colleges and universities to adopt revised STEM approaches, and, on the other hand, by encouraging the creation of whole new colleges, such as Olin, that are devoted from the outset to the kind of STEM education that is needed.

One way to do this is for Congress to appropriate approximately $65 million a year to NSF for five years to be awarded as prizes to colleges and universities that have dramatically increased the rate at which their freshmen STEM students graduate with STEM degrees and that demonstrably sustained the increase over five years. Awards could be offered in three tiers: $5 million for small colleges, $10 million for mid-sized ones, and $30 million for large universities. If Congress does not want to appropriate this money, it could instead require NSF to include as a factor in awarding research grants the performance of the university or college in addressing the problem of STEM switchouts and dropouts.

Believers in the Some STEM for All framework are correct in their conviction that getting STEM policy right is important to the future of the U.S. economy. But rather than continue down a road that has not produced the results needed, it is time for the Some STEM for All policy community to think anew and reflect on whether the standard assumptions and recommendations for STEM are really working or likely to work.

I argue that they are not, and that it is time for the nation to reorient its approach to STEM education and adopt and implement a coordinated STEM education strategy grounded in an All STEM for Some approach.

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