



# Slow Off the Mark

Elementary School Teachers and the Crisis in Science, Technology, Engineering, and Math Education

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Diana Epstein and Raegen T. Miller May 2011





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# Introduction and summary

You can't throw a stone without hitting a STEM initiative these days, but most science, technology, engineering, and math initiatives—thus the STEM acronym—overlook a fundamental problem. In general, the workforce pipeline of elementary school teachers fails to ensure that the teachers who inform children's early academic trajectories have the appropriate knowledge of and disposition toward math-intensive subjects and mathematics itself. Prospective teachers can typically obtain a license to teach elementary school without taking a rigorous college-level STEM class such as calculus, statistics, or chemistry, and without demonstrating a solid grasp of mathematics knowledge, scientific knowledge, or the nature of scientific inquiry. This is not a recipe for ensuring that students have successful early experiences with math and science, or for generating the curiosity and confidence in these topics that students need to pursue careers in STEM fields.

“No Common Denominator: The Preparation of Elementary Teachers in Mathematics by America's Education Schools” by the National Council on Teacher Quality, documented the need for more rigorous mathematics preparation of elementary level teacher candidates.<sup>1</sup> And in the two years since its release, very little has changed—despite evidence showing that elementary school students have higher achievement in mathematics when their teachers know more about how to teach math well.<sup>2</sup>

In this report, we focus on the selection and preparation of elementary school teachers, most of whom will be required to teach mathematics and science when they enter the classroom. It is elementary school mathematics and science that lay the foundation for future STEM learning, but it is elementary school teachers who are often unprepared to set students on the path to higher-level success in STEM fields.

In order to improve STEM learning, we must strengthen the selection, preparation, and licensure of elementary school teachers. We need higher standards for selection into teacher preparation programs—standards that include demonstrated proficiency in math and science at a level that is far higher than our current

pool of teacher candidates. Elementary grade teacher preparation programs must include more—and more rigorous—math and science courses in both content and pedagogy, and teacher candidates must perform in these courses at the high levels that we would expect of our students.

Furthermore, states must strengthen their licensure requirements so that teachers cannot obtain a license without passing the math and science sections of the exams. Finally, alternative certification programs should continue to recruit candidates who were STEM majors in college or are STEM professionals, and their licensure should be streamlined in order to get them into classrooms as soon as they are ready.

These steps represent a dramatic departure from current policy, but serious action is needed now in order to improve the prospects for our future global competitiveness. We cannot wait any longer to get serious about STEM policy. Strengthening our elementary school teachers in math and science is the first critical step in the right direction. To that end, we make five specific recommendations in this report:

- Increase the selectivity of programs that prepare teachers for elementary grades
- Implement teacher compensation policies, including performance-based pay, that make elementary teaching more attractive to college graduates and career-changers with strong STEM backgrounds
- Include more mathematics and science content and pedagogy in schools of education
- Require candidates to pass mathematics and science subsections of licensure exams
- Explore innovative staffing models that extend the reach of elementary level teachers with an affinity for mathematics and science and demonstrated effectiveness in teaching them

As we will demonstrate, improving the ability of our elementary school teachers to teach the facts, concepts, and procedures critical to success in STEM fields is required if our nation is to succeed in the globally competitive arena of the 21st century.



## Why should we care?

STEM education is a popular topic these days, commanding an ever-greater share of our national dialogue about education. In his 2011 State of the Union address, President Barack Obama called for training 100,000 new math and science teachers over the next 10 years. Furthermore, the STEM fields form the basis of much of the innovation that the president touted as crucial for American economic growth.

International tests demonstrate that U.S. students have fallen behind their international peers in math and science. The Program for International Student Assessment, or PISA, assesses reading, math, and science literacy among 15-year-olds in the 34 member nations of the Organization for Economic Cooperation and Development and 31 other countries and education systems. On the 2009 PISA exam in mathematics, the average score for U.S. students was 487, lower than the OECD average of 496. The United States had also scored lower than the OECD average in 2003 and 2006. On the 2009 mathematics exam, 17 countries had higher average scores than the United States, 5 had lower average scores, and 11 had average scores similar to those of the United States. On the 2009 science PISA exam, the U.S. average score was similar to the OECD average. Twelve OECD countries had higher average scores than the United States, nine had lower average scores, and twelve had average scores similar to those of the United States.<sup>3</sup>

Results from another international test, the Trends in International Mathematics and Science Study, tell a similar story. On the 2007 TIMSS mathematics exam, U.S. fourth- and eighth-graders scored higher than the TIMSS average, but behind a group of countries that includes Taiwan, Singapore, Japan, and Hong Kong. On the science TIMSS, U.S. fourth-graders scored above the TIMSS average but again lower than Taiwan, Singapore, Japan, and Hong Kong. U.S. eighth-graders also scored above the TIMSS average in science but behind a larger group of countries that included the same Asian countries but also England, Russia, and the Czech Republic.<sup>4</sup>

Perhaps more alarming is the fact that we have poured a tremendous amount of resources into STEM initiatives over the past couple of decades, yet our students' performance in math and science is still quite low. Scores on the national test, the National Assessment of Educational Progress, or NAEP, demonstrate that far too few U.S. students are at or above the proficient level in math and science. In 2009 only 39 percent of fourth-graders scored proficient or above in math, and 34 percent proficient in science. Similarly, only 34 percent of eighth-graders scored proficient or above in math, and only 30 percent in science.<sup>5</sup>

What's more, not only do current U.S. elementary school STEM education policies result in lower average student achievement overall in math and science, but they are especially damaging for low-income students who have less access to supplementary math and science instruction outside of school.<sup>6</sup>

Poor student achievement in science translates into dismally low adult scientific understanding.

Poor student achievement in science translates into dismally low adult scientific understanding. A 2009 Pew poll found that many Americans lack basic science knowledge on a variety of topics. For instance, while 82 percent of the public knew that GPS technology relies on satellites, only 65 percent knew that carbon dioxide is linked to higher global temperatures, and only 54 percent understood that antibiotics do not kill viruses.<sup>7</sup>

Beyond poor achievement, our students suffer from a persistent and damaging cultural bias against mathematics. A child who has difficulty with math is taught to believe that he or she is just not a "math person." In contrast, it is not an option as to whether or not one is a "reading person." All teachers know how to read, but not all teachers have confidence with basic math.

Indeed, many elementary school teachers are math-phobic, which puts them at a major disadvantage in teaching math and imparting confidence in their students. In fact, a recent study from the University of Chicago demonstrates that female first- and second-grade teachers' math anxiety has a negative effect on their female students, both in terms of their math achievement and in their endorsement of the gender stereotype that boys are good at math and girls are good at reading.<sup>8</sup>

Similarly, science education in the United States suffers the distracting intrusion of religious preferences. Courts have consistently ruled that creationism has no place in public school science classrooms and the scientific community has made clear that evolutionary biology should play a central role in science curricula.<sup>9</sup> Yet the cultural and political undertow keeps many science teachers from fully embracing the knowledge and norms of science.

Although evolution is not usually taught at the elementary school level, its treatment in higher grades illustrates the extent of the problem. According to a recent national survey of high school biology teachers, 28 percent introduce evidence that evolution has occurred, 13 percent explicitly advocate creationism or intelligent design, and 60 percent are neither strong advocates for evolutionary biology nor do they explicitly endorse nonscientific alternatives.<sup>10</sup>

These are distressing trends in U.S. education. In the next section of this paper we will explore one reason why the current fascination with STEM education is not translating into meaningful results.

## STEM to the rescue

The focus on STEM education began in 1958 with passage of the National Defense Education Act, a response to the Soviet Union's surprise launch of its Sputnik spacecraft that focused on increasing knowledge in math, science, and foreign languages. Reforms in curricula and policies led to the "New Math" of the 1960s. New Math's emphasis on abstract concepts and the underlying structure of mathematics may have seemed sensible to mathematicians, but it proved impossible to implement. Parents whose own educations had been satisfactory were puzzled by their children's struggles with set theory or modular arithmetic, for example. Elementary school teachers did not cope well with the New Math and failed to develop the skills to teach it successfully.<sup>11</sup>

The 1980s brought two important reports related to STEM education: The National Council of Teachers of Mathematics's "An Agenda for Action," which called for a larger focus on problem solving, the use of calculators, and a de-emphasis on calculus, and the more-famous "A Nation at Risk," which recommended a return to basic mathematics skills and better textbooks and highlighted poor teacher preparation and the shortage of math and science teachers.<sup>12</sup>

The debate intensified in 1989 when the National Council on Teacher Quality published the "Curriculum and Evaluation Standards for School Mathematics," which exemplified progressive education's focus on student discovery and conceptual understanding gained through inquiry. This kicked off the "math wars" of the 1990s, a battle between the approach advocated by this report and a more traditional back-to-basics philosophy of math education.<sup>13</sup> In 2008, the National Mathematics Advisory Panel called for a truce in the math wars by recommending content that students should master in each grade and remaining neutral on teaching methods.<sup>14</sup>

The truce is holding, it seems, as STEM initiatives are now abundant, and on the minds of academics and policymakers at all levels of the system. Some of these initiatives are making great progress in math and science education. The National Math and Science Initiative, for example, is identifying programs with proven

results in math and science education and is providing the funding to scale them up. Many large corporations and their philanthropic arms also support STEM programs and contests as a means of building their future workforce.

Case in point: The recently-created Change the Equation initiative is an effort by more than 100 corporate chief executives to improve STEM education.<sup>15</sup> Other prominent examples of corporate sponsorship include the Intel Science Talent Search (formerly the Westinghouse Science Talent Search), which each year selects the best high school science research projects from around the country, and the popular FIRST robotics competition.

Most existing STEM projects, however, are aimed at the secondary or university level. Even those initiatives designed to recruit more teachers with STEM backgrounds do not usually differentiate between elementary and secondary schools. A 2007 report from the National Academies, for example, suggests ways the United States can become more competitive in science and technology, including the recommendation to recruit 10,000 math and science teachers each year by offering merit-based scholarships in exchange for five years of teaching in a kindergarten-through-12th grade public school—without any singular focus on the elementary level.<sup>16</sup>

These STEM initiatives are worthy and useful, but the inadequate preparation of elementary school teachers is a “blind spot” in our portfolio of STEM programming.<sup>17</sup> Very few STEM initiatives focus explicitly on the need for better elementary level teaching in math and science, yet it is these early grades that lay the critical foundation for future student learning. Students’ interest in math and science is often stimulated at a young age, and building solid skills early on is essential for successfully progressing to higher-level subjects.<sup>18</sup>

What’s worse, current policies are clogging the pipeline to real STEM reform. To this we now turn.

# Current policies clog the STEM pipeline

The way we select and train our elementary school teachers is completely incompatible with our stated goals related to STEM careers, economic growth, and innovation. Not only are many elementary school teachers ill-prepared to teach mathematics and science effectively, but current policies favoring elementary grade teaching candidates with little appetite for mathematics and science is tantamount to an anti-STEM initiative. If we truly want to improve kindergarten-through-12th grade STEM education, then we need to critically examine current policies related to:

- Selection requirements for elementary grade teacher preparation programs
- Course requirements in those programs
- State licensure requirements

Let's examine each of these issues in turn.

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## Selection requirements

We do not select teacher candidates based on their ability to do math successfully. Many colleges and universities have only minimal entry requirements for education majors, and most post-baccalaureate teacher preparation programs do not select entrants based on math test scores. A recent National Council on Teacher Quality study of elementary teacher math preparation sampled 77 education schools and found that the most commonly used admissions criteria are a minimum grade point average (usually 2.5 or above), a high school or college transcript, and a minimum score on the mathematics portion of one additional test such as the Praxis I Pre-Professional Skills Tests, ACT, SAT, Graduate Record Examination, or a calculus/statistics Advanced Placement exam.

Moreover, 69 percent of the sampled programs require a basic skills test that only assesses knowledge on topics taught in elementary and middle school level math.

Some education schools do not require any tests for program admission, and most of those that do are assessing candidates at a proficiency level lower than high school. Only one program in the study's sample requires students to have mathematics proficiency above the basic level in order to be admitted.<sup>19</sup>

In other countries, standards for admission to teacher training programs put the United States to shame. A 2007 study by McKinsey and Company that looked at a sample of school systems around the world found that the top-performing systems were highly selective in admitting students to teacher preparation programs.<sup>20</sup> Teachers in South Korea come from the top 5 percent of their cohort, from the top 10 percent in Finland, and from the top 30 percent in Singapore and Hong Kong. Most prospective teachers in the United States are nowhere near this standard. In 2010, college-bound seniors who took the SAT and intended to major in education as undergraduates, the predominant manner of preparation for future elementary school teachers, had a mean score of 486 in mathematics. This puts them at about the 40th percentile.<sup>21</sup>

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### Preparation: Course requirements and content knowledge

Course requirements in teacher preparation programs are generally weak, both in terms of math content and pedagogy. The National Council on Teacher Quality's "No Common Denominator" report found a wide variety of requirements in its sample of 77 education schools.<sup>22</sup> States have different guidelines for elementary grade mathematics preparation, and the sampled schools differ both in course content and in the quantity of math courses required. Only 13 percent of the schools were judged as providing quality mathematics preparation. The report also found that many schools were using inadequate textbooks in their mathematics courses, and the content of courses generally lacked rigor.

Another recent study, the "Teacher Education and Development Study in Mathematics," compared the mathematics preparation of U.S. elementary and middle school teachers to that of other countries.<sup>23</sup> As part of the project, researchers assessed the mathematics content knowledge of a sample of future elementary school teachers at the end of their last year of teacher preparation. In content knowledge at the elementary level, future teachers from U.S. public institutions scored significantly lower than their counterparts in three of the other 14 countries, and had scores similar to Germany, Norway, Thailand, and Russia. Notably, the U.S. future teachers scored almost an entire standard deviation (100 points where the test mean

is 500) behind their peers in Taiwan and Singapore. In pedagogical content knowledge, meaning knowledge about how to teach mathematics, the future U.S. teachers fared better, though still significantly lower than Singapore and Taiwan.

Interestingly, the study found similar teacher preparation course-taking patterns in most of the countries in terms of the distribution of courses among formal mathematics, mathematics pedagogy, and general pedagogy. Yet only one-quarter of U.S. future teachers had taken a two-course calculus sequence, compared to 62 percent in Switzerland and 41 percent in Singapore.<sup>24</sup>

The authors of the “Teachers Education and Development Study in Mathematics” study suggest that international differences in future teacher knowledge are perhaps attributable to prior mathematics preparation in the K-through-12 system, and the selectivity of teacher recruits. Students in the United States enter teacher preparation programs with lower levels of mathematical knowledge (on average) than their peers from higher-performing countries, and the mathematics taught in the U.S. programs is often at a lower level.

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## Licensure requirements

Teachers in most states can pass the licensing exam without successfully passing the math portion of the test. States either do not report a math subscore, or the math subscore itself does not determine whether a candidate passes or fails the test.<sup>25</sup> Almost all elementary school teachers have to teach reading, math, and a host of other subjects. Not requiring teachers to demonstrate math knowledge before receiving a license is potentially sending thousands of teachers into classrooms each year who are ill-prepared to teach mathematics. This is something akin to conferring board certification on surgeons who demonstrate good bedside manner.

As of 2010, only two states—Massachusetts and Minnesota—had implemented policies designed to ensure that elementary school teachers were sufficiently prepared in mathematics. Massachusetts requires its elementary school teacher candidates to pass a mathematics content test before receiving a license, and this test is tailored to the mathematics needs of elementary level teachers. In Minnesota, it is not possible for teacher candidates to pass the certification test if they fail the math portion. None of the other states’ licensure requirements guarantee that new elementary teachers have the requisite level of mathematics knowledge.<sup>26</sup>



Furthermore, the passing scores on licensure exams tend to be quite low. Massachusetts is the only state that sets the licensure pass score at the mean score for all candidates that take the exam. Pass scores for all other states are below the mean.<sup>27</sup> States may fear that ambitious cut-scores or requiring passage of all subsections would radically limit their pool of potential teachers, but whatever their motive they tend to embrace policies that are inconsistent with the broader STEM agenda.

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## Science: Selection, preparation, and licensure

The situation in science is even worse. In recent years schools have devoted more time to math and reading because these subjects are always included in the standardized tests upon which state accountability systems are based. Science, in contrast, is often overlooked and given far less attention in the elementary grades. A 2004 survey of school districts around the country showed that 22 percent had reduced instructional time in science in order to make more time for reading and/or math.<sup>28</sup> Short-changing science is short-sighted policy for our nation when we know we must develop a pipeline of STEM professionals. An interest in science can develop at a young age, and learning the fundamental principles of scientific inquiry is critical to success in secondary science courses.

Science scores are rarely, if ever, considered in admission to elementary grade teacher preparation programs. Future teachers are usually required to take one or more science courses, but as with math the quality and quantity of these courses varies widely. The best data on the preparation and practices of elementary school teachers in science comes from the 2000 National Survey of Science and Mathematics Education.<sup>29</sup> This study included a random national sample of 655 teachers in grades K-through-5, all of whom taught science, and most of whom taught science and all other subjects in a self-contained classroom.

The study found that only 4 percent of these teachers had undergraduate degrees in science or science education. Ninety-two percent of the teachers had had college coursework in life science, but only 53 percent had coursework in chemistry, and only 62 percent in physics/physical science. Perhaps even more worrisome is that 23 percent had not had any coursework in science education.

Adequate preparation in science is critical in order to teach subject-specific content knowledge, promote conceptual understanding, and build students' fluency

Science scores are rarely, if ever, considered in admission to elementary grade teacher preparation programs.

## Ask the teachers

Percentage of elementary school teachers who consider themselves qualified to teach a range of subjects

	Not well qualified	Adequately qualified	Very well qualified
Life science	10	63	28
Earth science	13	64	24
Physical science	27	59	14
Mathematics	1	33	66
Reading/language arts	1	22	77
Social studies	5	43	52

Source: Report of the 2000 National Survey of Science and Mathematics Education.

with the fundamental processes that constitute the scientific method of generating new knowledge. Confidence is also very important. If teachers do not feel they are prepared to teach science, they may consciously or unconsciously devote more time to other subjects or avoid teaching more complicated scientific concepts. Yet many elementary teachers feel that they are not adequately prepared to teach science in their classrooms (see table).

# Recommendations and conclusion

The United States is not lacking in blue-ribbon commissions, panels, initiatives, and entire organizations focused on improving STEM education. Everyone seems to agree that we have a problem—that our country’s economic future depends, at least in part, on raising our kindergarten-through-12th grade students’ math and science achievement so that they can eventually progress into STEM careers. Where we are deficient, however, is in the will to reorient our education system toward a greater focus on high-quality math and science instruction in the early years.

In our recommendations, we largely follow the National Council on Teacher Quality’s suggestions for improving the quality of math and science teachers.<sup>30</sup> We focus explicitly on elementary school teachers because we believe this is the key, neglected lever on which all other STEM initiatives depend. Specifically, we recommend that Congress, state legislatures, and state boards of education reform their teacher training policies to:

- Increase the selectivity of programs that prepare teachers for elementary grades
- Implement teacher compensation policies, including performance-based pay, that make elementary teaching more attractive to college graduates and career-changers with strong STEM backgrounds
- Include more mathematics and science content and pedagogy in schools of education
- Require candidates to pass the mathematics and science subsections of licensure exams
- Explore innovative staffing models that extend the reach of elementary level teachers with an affinity for mathematics and science and demonstrated effectiveness in teaching them.

Let’s explore each of these recommendations in more detail.

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## Increase the selectivity of programs that prepare teachers for elementary grades

Highly successful organizations such as Teach for America show that there is an abundance of talented college graduates and career changers interested in teaching.

We must recruit higher-achieving students into the teaching profession, and these students should demonstrate high-level proficiency in all subjects, but especially mathematics and science. Basic labor market theory and some empirical research suggest that stiffer admission standards will reduce the supply of teacher candidates, but high-achieving college graduates and career-changers who are currently dissuaded by low admissions standards will take up part of the slack, excited about the prospect of being surrounded by similarly high-achieving peers.<sup>31</sup>

Highly successful organizations such as Teach for America and The New Teacher Project have shown us that there is an abundance of talented college graduates and career changers interested in teaching, but for whom traditional, nonselective preparation programs are anathema. In 2010 Teach for America, for example, received over 46,000 applications for 4,500 slots.<sup>32</sup> Moreover, highly selective programs have taken it upon themselves to bolster the ranks of STEM capable teachers. In 2004, Teach for America began a campaign to recruit applicants with STEM backgrounds, and by 2009 20 percent of applicants came from STEM fields.<sup>33</sup> In 2010, 22 percent of the teachers recruited by The New Teacher Project in New Orleans had a math or science background.<sup>34</sup> It seems that greater selectivity has an upside, and that it has not been fully tapped.

And there is good evidence that the downside of greater selectivity is often exaggerated. Greater selectivity would not be a problem to the extent that it removes from the pipeline those who complete programs but do not go on to teach. That up to half of candidates do not go on to teach suggests there is indeed slack in the system to be taken up by greater selectivity.<sup>35</sup>

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## Implement teacher compensation policies that make teaching more attractive to STEM college graduates and career-changers

The federal government has embraced this idea with the Teacher Incentive Fund, or TIF, a competitive program designed to help states and districts that wish to transform their compensation systems.<sup>36</sup> The TIF program's bipartisan appeal became apparent recently when it received a fiscal year 2011 appropriation of \$400 million while other domestic programs absorbed unprecedented cuts.

Folding performance-based pay and differentiated pay for elementary school teachers in shortage areas including mathematics and science into compensation systems will require sustained efforts at all levels. These efforts can take cues from specific ideas implemented in TIF sites and elsewhere. Dan Goldhaber, a University of Washington economist, examined compensation reform efforts and found that state-level activity was associated with success.<sup>37</sup> Efforts in Maryland's Prince George's County Schools, Pennsylvania's Pittsburg Public Schools, Ohio's Toledo Public Schools, and Colorado's Weld County School District Re-8 also highlight successful union-management collaborations around these kinds of compensation reforms.<sup>38</sup>

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### Include more mathematics and science content and pedagogy in schools of education

Traditional elementary grade teacher preparation programs should adopt a so-called "3/1 framework." This framework requires three mathematics courses on topics relevant for the elementary level, and one mathematics methods course for teaching elementary mathematics. In addition, we recommend that teacher candidates must receive strong grades (B or higher) in these courses in order to progress through the program.

For science, elementary grade teacher candidates should take courses that cover all aspects of science that will be addressed at the elementary level, meaning biology, chemistry, physics, and earth science. As with math, strong grades in science courses should be a requirement for completing the program.

Licensure requirements fall under the purview of state legislatures and state boards of education, and certain state-specific changes to statute and regulation would bring about this recommendation. The U.S. Department of Education can exercise existing waiver authority to provide incentives such as regulatory relief for movement in this direction. And the U.S. Congress can signal approval of such movement by authorizing small competitive programs or through annual appropriations.

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## Require candidates to pass the mathematics and science subsections of licensure exams

It is unacceptable that we set high standards for our elementary school students but fail to do the same for those students' future teachers. All states should raise their passing score on licensure exams, and all states should require that teacher candidates pass the mathematics and science portions of the tests. One would hope that states do not license drivers who fail to demonstrate adequate mastery of a maneuver as fundamental as a left turn, for example, and there is no mystery in the idea that candidates for teacher licensure should have to earn satisfactory scores on licensure test subsections corresponding to basic domains of knowledge. Reauthorization of the Higher Education Act, for example, would be an appropriate legislative vehicle for Congress to incentivize states to reform their policies in this respect.

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## Explore innovative staffing models that extend the reach of elementary level teachers with an affinity for mathematics and science and demonstrated effectiveness in teaching them

Rocketship Education, a network of charter schools in California, has pioneered innovative uses of human capital in schools.<sup>39</sup> In the Rocketship staffing model, elementary school teachers specializing in math and science teach 100 students (four blocks of 25 students), thus extending the reach of teachers with an affinity for math and science and laying the groundwork for differentiating compensation. Similar staffing approaches could conceivably be extended to traditional elementary public schools. While we still believe all elementary level teachers should be proficient in math and science content and pedagogy, schools should consider exploring new ways of organizing both teachers and time so students can receive the strongest possible instruction in STEM subjects.

# Conclusion

Few would argue that we need to improve our students' performance in math and science, both to produce citizens who are STEM-literate and to grow the STEM workforce that is required for future global competitiveness. The math and science competency of elementary school teachers is clearly a blind spot in our country's STEM policy.

Elementary level learning lays the foundation for later success, and many of our elementary school teachers do not currently have the requisite knowledge and skills to deliver high-quality math and science instruction. Strengthening the selection, preparation, and licensure of elementary school teachers in math and science is critically important if we are to improve our students' achievement in STEM fields and generate well-trained STEM professionals.

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