

EDUCATION

Preparing Future Math Teachers

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Poor precollege math abilities, and too little emphasis on college-level math, can reduce the number of highly capable math teachers.

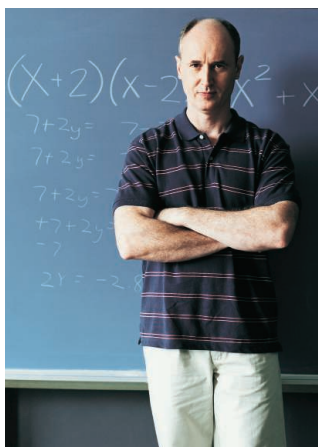
The U.S. President's Council of Advisors on Science and Technology recommends that the federal government provide support over the next decade to recruit and train at least 100,000 new science, technology, engineering, and mathematics (STEM) teachers of middle school (ages 11 to 13) and high school. Their strong academic backgrounds should include both "deep content knowledge in STEM subjects and mastery of the pedagogical skills required to teach these subjects well" (1).

How can this be accomplished for middle school mathematics teachers? What is the role for recruitment versus what must be accomplished through preparation? In part, the answer requires an understanding of what a well-qualified middle school mathematics teacher is. This has been a puzzle for over 40 years (2). That teachers need to have "some" knowledge of mathematics is always mentioned, but there is little agreement as to how much. Some have suggested that a strong background is sufficient, as evidenced by proposals to place college-educated individuals with degrees in mathematics in the classroom without any or with very limited teacher training (3, 4).

We address this issue by reexamining data from the 2010 Teacher Education and Development Study in Mathematics (TEDS-M), a 16-country survey of math teachers-in-training near the end of their final semester. TEDS was conducted by the International Association for the Evaluation of Educational Achievement (IEA) with an eye to developing international benchmarks for teacher preparation. This is similar to what was done for K–12 (primary and secondary) curricula via the IEA Trends in International Mathematics and Science Study (TIMSS).

TEDS-M Results

U.S. middle school mathematics teacher preparation does not produce teachers with an internationally competitive level of mathematics knowledge. U.S. future teachers' TEDS scores straddle the divide between countries whose middle school students do better than the United States on international tests such as TIMSS, and those who do not (5, 6). (The only exception is Malaysia, which outperformed the United States in TIMSS but fell below the United States on TEDS).



Who is best prepared to teach middle school mathematics?

This relatively weak TEDS performance suggests that teacher quality may be the Achilles heel, as more than 40 U.S. states move to implement the mathematics Common Core State Standards (www.corestandards.org). Will teachers have the needed knowledge to implement these internationally benchmarked standards that are more rigorous than previous standards which were "a mile wide, inch deep" [p. 122 of (7)]?

TEDS also documented how future teachers were prepared, e.g., which courses were taken (8). Generally agreed-upon cognitive competencies necessary for teaching mathematics encompass: (i) mathematics knowledge, (ii) pedagogical knowledge related to the teaching of mathematics, and (iii) general pedagogical knowledge related to instructional practices and schooling more generally (9, 10).

Future middle school teachers in all TEDS countries provided course-taking data that allowed us to characterize the percent of teacher-preparation course work in each of the three areas. The two highest-achieving countries, Taiwan and the Russian Federation, had on average a ratio across the three areas of roughly 50%:30%:20%. Roughly half of students' teacher-relevant efforts were in mathematics. By contrast, the estimated ratio for the United States was about 40%:30%:30%. The percentage of coursework on mathematics pedagogy was the same, but the general

pedagogy emphasis was higher in the United States, which balanced out the lesser focus on formal mathematics (11).

Who Enters Teaching?

The pool of K–12 graduates from which the United States obtains its future teachers is weak compared with their peers internationally. On average, U.S. future teachers as they enter teacher preparation programs have been exposed to a less-demanding K–12 curriculum and have lower levels of mathematics knowledge than those in other countries. This promotes a vicious cycle. Weak K–12 mathematics curricula taught by teachers with an inadequate mathematics background produce high school graduates who are similarly weak. Some graduates then become future teachers who are not given a strong mathematics preparation at the college level. They then teach, and the cycle continues.

TIMSS eighth-grade mathematics data can define the pool from which future teachers are drawn. This allows estimation of country selection effects, the relative level of mathematics knowledge with which a country's typical future teacher enters teacher preparation.

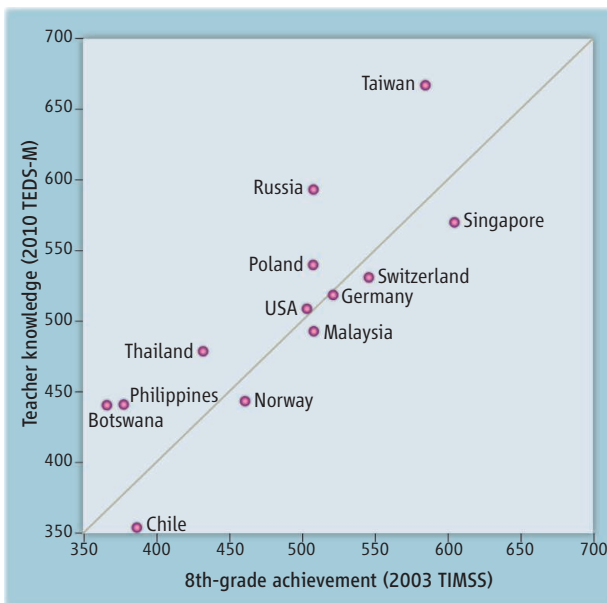
If Taiwan and Singapore were to select their average eighth graders (as represented by median performance on each country's distribution for the 2003 TIMSS) to become future middle school mathematics teachers, the United States would have to draw its future teachers from above their 75th percentile to be comparable to those from Taiwan and Singapore in their knowledge of mathematics (5). It is likely that, in some countries, future teachers are recruited from the upper end of the national distribution, through higher teacher salaries relative to other mathematics-oriented professions, which further exacerbate the differences (12). To obtain a well-prepared and well-qualified teaching force, any country must attend to who is recruited and selected.

The Role of Preparation

Another way to explore this issue is to compare the knowledge of potential future middle school teachers of mathematics, as reflected by TEDS, with the average eighth-grade mathematics achievement, as found in TIMSS (13). The strong relation

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Teacher preparation versus student scores in mathematics. TEDS scores for future middle school mathematics teachers versus TIMSS scores for eighth graders. See SOM.

between TEDS and TIMSS [the square of the correlation coefficient (R^2) = 0.70, $P < 0.0004$] reflects how selection and/or recruitment based on knowledge before entry into teacher training relates to future teachers' knowledge when exiting from training (see the chart). Because both tests use the same scale, the diagonal line in the chart represents what would be observed if the mean TIMSS score for a country yielded the equivalent mean TEDS score (14). Some countries' mean TEDS scores are higher than would be expected from their mean TIMSS scores (above the diagonal line); others' are lower [supporting online material (SOM) (15)].

What might explain why countries fall above or below the line? Above-the-line countries may recruit future teachers from high school graduates who were in the upper end of their country's eighth-grade TIMSS distribution. Differences in course requirements of the preparation programs may also play a role. Every preparation program in every country included course work in each of the three broad areas described above. What differed was the relative emphasis given each area. Among those countries above the line, almost half (49%) of courses related to teacher preparation that were taken was devoted to mathematics, with only 21% emphasizing general pedagogy. For countries below the line, mathematics was given, on average, 37% emphasis with 28% emphasis on general pedagogy (see SOM).

To look more closely at the United States, each institution's average TEDS score was

plotted against the average SAT (a standardized college admissions achievement test) mathematics score for the institution's TEDS-participating students (16). Across the more than 80 randomly sampled public and private teacher preparation institutions, 56% were above the line and the rest were on or below the line. A pattern of coursework emphasis was found similar to that described for all TEDS countries. Future teachers in U.S. institutions above the line allocated, on average, about 40% to mathematics and 28% to general pedagogy. Below the line, the averages were about 30% for mathematics and 34% for general pedagogy. The 9% difference for mathematics courses was statistically significant ($P < 0.0001$) (see SOM).

What to Do

The implication given the relatively weak U.S. K–12 mathematics curriculum is that recruitment of future teachers must come from the upper end of the U.S. distribution of mathematics performance in order to be somewhat competitive with high-achieving countries. However, this may not be feasible if current efforts to raise salaries for such individuals are not realized. In addition, the data summarized above also highlight the importance of emphasizing courses in mathematics in the preparation of such teachers.

Thus, the solution for the United States lies in a combination of recruiting those who have strong quantitative backgrounds together with a greater emphasis on rigorous mathematics in teacher preparation. The latter needs to be driven by tougher middle school mathematics teacher certification requirements, which are set by state policy. Perhaps it is time to consider something like a “Common Core” for teacher preparation, to provide more rigorous, demanding, internationally benchmarked preparation standards for mathematics teachers. This effort might be led by the National Governor's Association and the Council of Chief State School Officers, the same two groups responsible for the Common Core State Standards Initiative. A long-term and better solution is to break the cycle of mediocrity in which

we find ourselves. The Common Core State Standards are one promising new component aimed at improving student learning.

References and Notes

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8. Future teachers indicated whether they had studied each listed topic on the survey. Most listed under university-level mathematics likely represent a course, e.g., linear algebra or beginning calculus. The topics listed for mathematics pedagogy, for example, mathematics instruction, affective issues in mathematics, and general pedagogy (e.g., history of education and educational systems, and assessment and measurement) might not be entire courses, as one course could cover multiple listed topics.
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14. The line was defined as equal scores on both measures, i.e., TIMSS and TEDS (see SOM).
15. Four TEDS countries (Germany, Poland, Switzerland, and Thailand) did not participate in the 2003 TIMSS but did participate in the 2003 Programme for International Student Assessment (PISA), a comparable international standardized assessment. TIMSS scores for these countries were imputed based on the TIMSS-PISA relation among all countries that participated in both 2003 assessments. Georgia and Oman were omitted as they did not participate in either TIMSS or PISA. See SOM.
16. The SAT and TEDS scores were rescaled to have a mean of 0 and a standard deviation of 1. Where only scores on the American College Testing standardized college admissions exam were provided, these were converted to SAT equivalent scores. See SOM.

Supporting Online Material

www.sciencemag.org/cgi/content/full/332/6035/1266/DC1

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