Multiplication Tables? Dismal State of U.S. Mathematics Education

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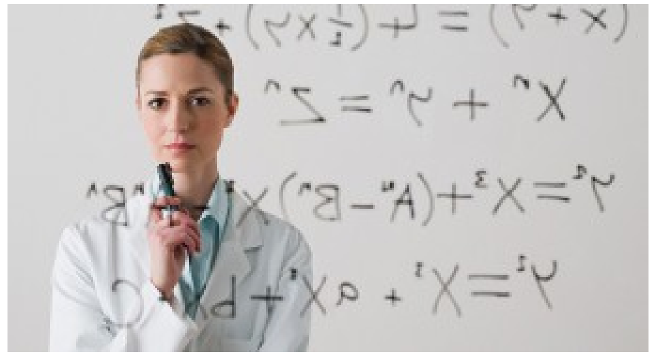
It always shocks me to see high school students struggling to solve simple arithmetic problems. I happened to casually glance at the algebra homework of a ninth grader one day and saw "3×7 =" written next to a graphing question. Evidently, he did not immediately know the answer and was probably looking for a calculator. I later learned that this student was almost failing the algebra course, but I also could not help but wonder how much trouble the actually failing students were having. It simply seemed inefficient to me that these students were trying to learn high school math, which is best learned with a solid foundation of fundamental concepts,when they couldn't remember the math they were supposed to have mastered six years ago.



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Math Education

The United States is one of the world's most technologically advanced countries, yet our mathematics program, especially at the secondary level, lags behind those of other industrialized countries [1][2]. Without a solid math background from grade school, the majority of adults in the US lack basic number sense skills – according to a poll conducted by the Center for Economic and Entrepreneurial Literacy almost 80% of adults interviewed did not understand the magnitude of a trillion [3]. These people may not completely understand the true size of the US's national debt or deficit, since for them, the figures may just seem like any big number.

Given American students' poor performance in math compared to other countries, it is unsurprising to find that the US tried a series math reforms throughout the latter half of the 20th century. Until 1960's, the predominant way of teaching math, often known as the "traditional" approach, emphasized memorization of basic facts and standard algorithms at the elementary level, followed by an endless array of exercises to reinforce the information. The rote memorization mindset continued through high school, and even into college; it was not uncommon to see a college calculus class that mainly focused on integration formulas and differentiation rules rather than on the fundamental meaning and purpose of derivatives and integrals [4]. Textbooks presented few problems that went beyond substituting into given algorithms, and teachers rarely explained or even mentioned the reasons and principles behind these algorithms. Consequently, math often appeared as a random collection of formulas to students. Critics have called this traditional method "parrot math" to stress that while students eventually could reproduce most of the basic skills they were taught, they lacked any in-depth understanding of what they were learning [5].

In the 1960's, a radical change in the curriculum occurred in the US as a response to the Sputnik crisis, which spawned the Space Race against the Soviet Union. There was a general fear that the "traditional" math curriculum was not adequate to produce engineers that were well- grounded in advanced math. The National Science Foundation thus proposed "new math", which required students to learn abstract math concepts as early as elementary school, often before mastering basic computational skills. Set theory and abstract algebra, which were typically topics studied by advanced math undergraduates, made appearances in elementary school textbooks. Educators justified these new curriculum additions by claiming that students would grasp abstract math more easily in higher education if they were exposed to it earlier, although they did not make any explicit provisions for students who did not intend to further study science or engineering after high school [6].

Unfortunately, it was extremely difficult for students to process the abstract concepts, especially since they had very little concrete math background to build upon. For example, without a clear understanding of basic addition facts, ideas such as the Commutative Property of Addition seemed strange and unnecessary to students. According to Piaget's theory from developmental psychology, children generally do not develop the ability to perform abstract reasoning until adolescence, so the "new math" essentially tried to teach concepts that most children were not cognitively ready to learn [7].

As in the traditional approach, students had weak math foundations because they did not completely understand the ideas of the "new math." However, the new approach was even less effective in the long-run because abstract mathematical concepts had no common applications in the real world, whereas traditional arithmetic operations were at least used in day-to-day tasks. Furthermore, the teachers themselves often did not completely grasp what they taught since they were generally not exposed to abstract mathematics in secondary school, so explaining the concepts to elementary school children was nearly impossible. Students often came out of elementary school having a vague idea about technical advanced math terminology but without the ability to compute basic multiplication facts. Ultimately, the experiment was a failure, and most schools almost immediately switched back to the traditional approach in the 1970's [6].

The traditional approach continued to be the method of choice in schools across the US for another twenty years, and before long, arguments about students' shallow understanding of math formulas again emerged. A new movement came into focus in the late 1980's when the National Council of Teachers of Mathematics (NCTM) introduced a different set of standards that emphasized mathematical inquiry over routine calculations. Memorization of algorithms was nearly eliminated, calculators were encouraged, and students were asked to "discover" their own methods of doing basic operations. This "constructivist" proposal gave rise to many new textbooks in the 1990's, and it became popular as several large school districts adopted these new curriculum reforms [8].

Unfortunately, students and teachers were shortly faced with a new problem. To make the curriculum seem more modern, many programs encouraged heavy calculator use and did not require students to memorize basic facts. However, without adequate practice in these essential computational skills, students began to have trouble with even basic arithmetic, and were rarely able to do even slightly complicated problems without technology. Also, without a methodical way to add fractions, multiply two-digit numbers together, convert between percents and decimals, or carry out other similar operations, students usually ended elementary school mathematics unable to perform these essential operations. Visualizing two fractions being added, for example, was preferred over more algorithmic approaches but only works practically for simple cases; with a problem like $2/13 + 5/16$, intuition quickly breaks down and one must use more general methods [9]. While calculators have made tedious arithmetic unnecessary, basic computations show up frequently in numerous subjects that students may pursue later on, and in any case, it would be highly inconvenient for people to rely on a calculator for calculations that could be quickly done mentally with adequate practice.

Furthermore, perhaps as an attempt to avoid traditional methods, books commonly used variants of the standard algorithms for operations such as multiplication, division, and fraction addition. Besides being usually longer and more time-consuming, these "new" algorithms also misunderstood the NCTM reform's main objective: the goal was to help students understand math by finding alternatives to the traditional approach, not to replace existing algorithms. Incorporating an antiquated, inefficient "lattice" system for multiplying instead of the standard algorithm, for example, neither sped up the computation nor helped the student understand multiplication [10].

With all these unsuccessful changes in math programs over the past 50 years, it is not surprising that American students are behind their international counterparts in mathematics. But we rarely think about why students from other countries can learn math more thoroughly. A lengthy study done by Ginsberg and colleagues followed the math education system in Singapore, which uses a system that would be undoubtedly classified as "traditional", yet is consistently ranked at the top among other countries by several international tests [11]. An internationally recognized program, "Singapore Math", is based on the Singapore curriculum and has also found much success by the schools that have tried it [12]. By investigating the principles behind the Singapore math curriculum, the authors found numerous flaws in our own math education system that makes our methods weaker, even though they are based on the same "traditional" approach as those of Singapore's system [11].

The first problem in our math curriculum is its lack of specific and unified standards. Each state is free to make its own curricula, and the NCTM guidelines are vague at best; they define objectives for a range of grade levels, and therefore different states vary greatly in suggesting when basic concepts are introduced. The inconsistent structure hinders textbook companies' efforts of developing effective programs. It also becomes harder to determine the quality of new programs because the states have distinct assessment methods that influence the results of pilot- program studies. Singapore's curriculum, on the other hand, is easy to describe because it is nationalized and unified. It is therefore much easier to produce learning materials that work for all schools and to evaluate the effectiveness of the overall curriculum [11]. While a completely standardized system is less feasible in the US because of its large size and diversity, there should be more specific national standards that prevent states from producing greatly differing curricula.

The second issue with American math education lies with the textbooks' contents. Most basic math textbooks have exercises that require little thought from the student, such as one-step formula plug-ins. Students thus cannot readily apply the principles they learn to more complicated multi-step problems because they are not usually exposed to anything beyond their textbooks' rather simple exercises [4]. Singapore's textbooks, on the other hand, have basic drills as well, but move on to more challenging problems that apply the newly-learned concepts. By thinking through more involved questions, students master the basic procedure while developing their problem solving skills [11].

A related problem is that American curricula try to cover too many concepts in a single year. Partially, this is the result of the textbook publishers' attempts to satisfy as many standards and teacher demands as possible, which ultimately stems from the lack of curriculum centralization. While Singapore's standards only require about 15 topics per grade level, some state curricula contain over 50 topics to be covered in a school year [12]. Chapters and lessons therefore tend to be shorter and less in-depth. Although exposure to a diverse range of topics can arguably be beneficial, such a wide array of topics prevents deep comprehension of any specific topic. Therefore there is no time to develop the problem solving skills needed to tackle more complicated problems [11]. Middle and high school curricula tend to be similar in terms of their lack of depth. For example, Lockhart describes precalculus as a "senseless bouillabaisse of disconnected topics," many of which are glossed over because they are not introduced in a meaningful context [4].

Another serious weakness is the lack of qualified teachers who teach grade school math. Singapore's teachers must be certified through stringent exams before they even enter an education program, where they are paid a salary that is comparable to that of actual teachers. In contrast, prospective US teachers have the lowest math SAT scores on average out of all college majors. It is difficult to expect that the very individuals who did not thoroughly master math in school would be able to produce competent math students. Singapore teachers also undergo a rigorous professional development program in addition to extensive annual training in new skills. Meanwhile, US teachers only attend short workshops, despite the fact that these workshops are "widely admitted to be ineffective for changing practice", and teachers are not required to pass very stringent exams. In fact, the exam for certifying 6th grade teachers is easier than the exams given to Singapore sixth graders [11].

Tailoring the curriculum to students of different abilities, commonly called "tracking," is also important to ensure that all students master the material, not just the most able ones. A study showed that programs that offered more comprehensive tracking systems scored higher on math achievement tests, even after adjusting for student backgrounds [13]. Singapore addresses this problem by providing a complete alternative program for struggling students that focuses more on repetition and is taught by well-qualified teachers. By contrast, while the US provides resources for less able students, most special programs for slower math students in the US follow no real framework; students who fall behind are generally put into unofficial "extra-help" classes that are taught by aides who often have not earned a college degree. If all citizens are to have good basic math skills, then the needs of all students must be addressed and equal attention should be given to those who require more time or a different approach to grasp the material [11].

The solution to the problematic American curriculum is not as simple as just converting to the Singaporean model. Students that have already used American textbooks for a long time may not have all the skills necessary to progress to the next level in the Singapore curriculum, since the order and depth of topics are likely to differ. Also, since each level of the Singapore curriculum assumes knowledge of concepts taught in previous levels, any conceptual holes in American students' knowledge would prevent thorough understanding of the new topics introduced [11]. Finally, a sudden transition to more complicated and problem-solving based questions could initially be extremely difficult to students who are more accustomed to the American textbook exercises. A gradual change would be more appropriate, but then choosing the ideal resources to facilitate this change becomes a difficult task.

Newly implementing the program for first-grade students is not much more straightforward. Although students may yet not be accustomed to the "American way" like older students are, there are still other differences that prevent a smooth transition. As similar as the resources may be, the quality teachers will still differ between the two countries. The Singapore program presumes training in important methods used throughout the program, which in turn presumes a level of mathematical competence that may be higher than that of many US teachers. A lengthy professional program to train teachers in the US is conceivable but would be extremely expensive and require a large commitment that teachers' unions may resist [11]. Furthermore, the amount of time spent on math and science in school is vastly different between the two countries. Not only is the average school day in Asian countries longer, but also the proportion of time spent on math in school is also much greater in Asian schools. Unless more drastic reforms like lengthening the school day are considered, schools that plan to adopt a Singaporean math program must find ways to accommodate the greater required time commitment without significantly affecting the normal structure of the school day [14].

American schools may not be able to effectively adopt a close duplicate of the Singapore program, but they can certainly implement elements that make the Singapore curriculum successful. Greater unification of standards across states would allow national textbook companies to provide more focus in their textbooks, as well as make reforms much simpler to carry out and assess. A more comprehensive track can be produced for students with greater trouble, and ideally, such classes are taught by qualified teachers. While the abilities of American teachers will not suddenly change, more substantial professional development programs rather than short, occasional workshops can improve how well they teach the new material. Furthermore, standards for future teachers should increase to ensure that the new generation of teachers are mathematically confident themselves before they try to present their knowledge of math to their students. While we do not need a population of scientists and mathematicians, all people should be able to know enough mathematics to understand how numbers are used in everyday life, such as for basic tax accounting or recipes. With these reforms in mind, we can envision a society in which statistics mean more to everyone than just vague numbers to spice up an article. Perhaps then, young students will master their multiplication tables sooner, so that rather than being stuck on basic facts, they can begin to build the critical thinking skills necessary to become mathematically literate citizens.

This article was originally published in The Science in Society Review (http://www.thetriplehelix.org/what-we-do/the-science-in-society-review) [2] at Yale University (http://www.thetriplehelix.org/chapters/north-america/yale-university) [3]by The Triple Helix Inc (http://www.thetriplehelix.org/) [4]. Follow The Triple Helix Online on Twitter (http://www.twitter.com/tthepub) [5] and join us on Facebook (http://www.facebook.com/triplehelixonline) [6]

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