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WORLD-CLASS HIGH QUALITY MATHEMATICS EDUCATION FOR ALL K-12 AMERICAN STUDENTS

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Dedicated to Professor Evelyn M. Silvia, University of California, Davis
(February 8, 1948 – January 21, 2005)

Abstract. In September 1989, the United States' Governors Conference in Charlottesville, Virginia set an ambitious goal by declaring that "By the year 2000, United States students will be first in the world in mathematics and science achievements". However, recent results of the 'Programme for International Student Achievement' and 'Trends in International Mathematics and Science Study' indicate that the United States students' achievements in mathematics are far below world class standards. This paper seeks to discuss issues in an international context related to the goal of creating world-class high quality mathematics education for all K-12 American students. In particular, the author also shares his reflections and depicts lessons from Singapore's success story in mathematics education.

Key words: Mathematics Achievement; International comparisons; PISA; Singapore Educational System; Standards; TIMSS

1. INTRODUCTION

The United States (U.S.) is viewed as a global leader in many aspects, including finance, medical research, higher education, sports, and scientific and technological advancements. And yet, according to 'Programme for International Student Achievement' (PISA) and 'Trends in International Mathematics and Science study' (TIMSS), the U.S. is still very far from being world class in K-12 mathematics and science education (Lane, 1996; Kaiser, et al., 1999; Ahuja, 2003; Braswell, et al., 2004; Gonzales, et al., 2004; Martin, et al., 2004; PISA Website; TIMSS Website).

In September 1989, the U.S. Governors Conference in Charlottesville Virginia set up an ambitious goal by declaring that "*By the year 2000, United States students will be first in the world in mathematics and science achievements*". That same year, the U.S. Department of Education announced a set of eight goals, and its fifth goal was that "*U.S. students will be first in the world in mathematics and science achievements*" (U.S. Department of Education, 1989). However, this ambitious goal is yet to be achieved.

There are several reasons for why the U.S. ought to have world-class school mathematics education. The Glenn (2000) commission observed four important and enduring reasons to achieve competency in mathematics and science: (i) the demands of our changing economy and workplace, (ii) our democracy's continuing need for a highly educated citizenry, (iii) the vital links of mathematics and science to the nation's national security interests, and (iv) the deeper value of mathematical and scientific knowledge. The commission recommended that all students must improve their performance in mathematics and science if they are to succeed in today's world and if the U.S. is to stay competitive in the integrated global economy. In fact, the

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commission believed that "*competency in mathematics, both in numerical manipulation and understanding its conceptual foundations, enhances a person's ability to handle the more ambitious and qualitative relationships that dominate our day-to-day decision making*". A powerful mathematics education system would also help in: (i) strengthening democracy by creating an informed adult population, (ii) empowering individuals and enabling them to develop toward their potential, and (iii) providing a sound basis for continuing national prosperity (Schmidt, et al., 1998). These three reasons involve political, personal and social, and economic goals.

The need for providing excellent mathematics education has increased in the global village of the 21st century. Rising global competition, workplace opportunities and challenges require better-educated workers who are adept at reasoning, problem solving, analyzing, and making sense of things. Having a deep understanding of mathematics is vital for achieving these skills. The ability to approach problems logically, to apply reasoning to decision making, and to understand how things work are exactly the kinds of skills that should be developed through meaningful mathematics and science education. Today's students must therefore master high-level mathematical concepts and complex approaches to solving problems to be prepared for college and careers of the 21st century, as well as the demands of everyday life (CBMS, 2000).

One can argue that "*the American K-12 system is failing to provide the mathematics and science skills necessary for kids to compete in the 21st century workforce, and the U.S. higher education system cannot produce enough scientists and engineers to support the growth of the high-tech industry that is so crucial to economic prosperity*" (AeA, 2004). The U.S. Secretary of Education Rod Paige admitted: "…*Unfortunately, we are average across the board compared to other industrialized nations. In the global economy, these countries are our competitors - average is not good enough for American kids*" (Paige, 2001). As stated in the Wall Street Journal on October 7, 2004: "*American companies don't simply go to foreign countries for inexpensive labor; they are increasingly going abroad to find skills that aren't available, or plentiful, in their own backyard*".

In 2002, the U.S. Secretary of Education Rod Paige signed a six-page memorandum of understanding with Singapore Minister of Education Teo Chee Hean in which the U.S. and Singapore agreed to help each other improve mathematics and science education (Hoff, 2002). Mr. Paige said in his statement about the agreement that "*Singapore's students score among the highest in the world in mathematics and science and there is much we can learn about its system of education which leads to such high achievement*" (Hoff, 2002). It may also be argued that "*Singapore's elementary mathematics teachers, like other elements of Singapore's mathematics education system, are superior in overall quality when compared to their U.S. counterparts*" (Ginsburg, et al., 2004, p.118). More than one hundred school districts in the U.S. have been experimenting in their schools with several features of Singapore's mathematics curriculum, teaching methods, and text books (Viadero, 2000; Hoff J. D., 2002). Some of such major ongoing pilot projects are Montgomery County Public Schools (Maryland), Baltimore City Public Schools (Maryland), Peterson (New Jersey), and North Middlesex (Massachusetts).

An awareness of Singapore's success story will help us to share its cultural and educational practices and traditions. Singapore, meaning 'lion city', a highly developed and successful free market economy enjoys a remarkably open and corruption-free environment, stable prices, and a per capita GDP equal to that of the Big 4 West European countries. Like the U.S., Singapore too is multiethnic, multi religious, multilingual, and a democratic nation. It is a small island - 26 miles in length and 14 miles in breadth - and has a total land area of about 228 square miles. It was discovered in 1819 by the British, and became a part of Malaysia in 1963. Two years later, Singapore became an independent city-state-nation. Singapore became developed and prosperous in the last few decades. Singapore's Gross Domestic Product rose from $300 in 1970 to $27,800 in 2004. Its economy depends heavily on exports, particularly in electronics and manufacturing. Its current population is about 4.4 million with a population density of 18,261 per square mile. It is ethnically diverse with 77% Chinese, 14% Malays, 8% Indians and 1% of other ethnic groups. The general literacy rate is 93.7%. All children in Singapore are required to study two languages: English and their mother tongue. It has four national languages, though English is the primary language of instruction for all subjects except mother tongue.

This paper seeks to discuss issues in an international context related to the goal of creating world-class high quality K-12 mathematics education in the U.S. Section 2 illustrates the international perspective of American schools' mathematics education. Section 3 compares mathematics education in the U.S. and Singapore. Section 4 opens with observations and reflections of the author and goes on to look at the features that make Singapore number one in mathematics education in the world. The last section explores how the U.S. can achieve its goal of creating a world-class mathematics education system in which its students will be top in the world in mathematics achievements.

2. U.S. SCHOOL MATHEMATICS FROM AN INTERNATIONAL PERSPECTIVE

An international comparison of the U.S. students' achievements in mathematics is conducted by 'Programme for International Student Assessment' (PISA) and 'Trends in International Mathematics and Science Study' (TIMSS). It may be noted that originally TIMSS stood for 'Third International Mathematics and Science Study'. These international studies allow the U.S. to compare its students' performance in mathematics to that of other countries. PISA uses an age-based sample and tells us about the mathematical literacy of 15-year-olds, while TIMSS uses grade-based samples and reports on curricular achievements in mathematics. In 2003, the number of countries which participated in PISA and TIMSS were 41 and 46 respectively. Incidentally, India and China (mainland) did not participate in these international studies. While Singapore participates in TIMSS, it does not participate in PISA.

PISA is an international educational research study conducted every three years by the 'Organization for Economic Cooperation and Development' (OECD) (PISA Website). Table 1 show that its participants in 2003 included all 29 of the OECD countries and 10 non-OECD countries. But, the international average of 500 reported was based only on these 29 OECD countries. Its emphasis is on the 15-year old students' ability to apply a range of knowledge and skills in mathematics to a variety of problems with real-life contexts. In fact, its goal is to answer the question "what knowledge and skills do students have at age 15?" taking into account schooling and other factors that may influence their performance. Results of PISA 2003 in Table 1 show that on the mathematics section, the U.S. ranked 24^{th} out of the 29 member nations of OECD, dropping below Poland, Hungary, and Spain in the three years since the previous assessment. For further details, see Lemke (2004) and the PISA Website.

Table 1: *Average Combined Mathematics Literacy Scores in PISA* 2003

Rank	OECD countries	Score	Rank	OECD countries	Score
1	Finland	544	**24**	**USA**	**483**
2	Korea	542	25	Portugal	466
3	Netherlands	538	26	Italy	466
4	Japan	534	27	Greece	445
5	Canada	532	28	Turkey	423
6	Belgium	529	29	Mexico	385
7	Switzerland	527			
8	Australia	524		OECD COUNTRIES AVERAGE: 500	
9	New Zealand	523		**NON-OECD COUNTRIES**	
10	Czech Republic	516	**1**	**Hong Kong, China**	**550**
11	Iceland	515	**2**	**Liechtenstein**	**536**
12	Denmark	514	**3**	**Macao-China**	**527**
13	France	511	**4**	**Latvia**	**483**
14	Sweden	509	5	Russian Federation	468
15	Austria	506	6	Serbia & Montenegro	437
16	Germany	503	7	Uruguay	422
17	Ireland	503	8	Thailand	417
18	Stovak Republic	498	9	Indonesia	360
19	Norway	495	10	Tunisia	359
20	Luxembourg	493			
21	Poland	490		SOURCE: PISA Website	
22	Hungry	490			
23	Spain	485			

TIMSS is an international educational research study conducted every four years, comprising over half a million students across 5 continents and 46 countries. TIMSS 1995, 1999 and 2003 were projects of the International Study Center at Boston College. TIMSS International averages are generally based on 46 countries including 13 industrialized countries. It analyzes background information on the aims of school mathematics and their curricula, the delivery of instruction including textbooks and classroom practices, the students' attitudes and their mathematical achievements, the amount of parental support, and the qualification and training of teachers, among other information (TIMSS Website). TIMSS also reviews video-taped lessons prepared from classrooms in industrialized nations including the U.S., Germany, and Japan (NCES, 2000). All TIMSS data are based on the performance of both public and private schools in the U.S. and other participating countries. Achievement test scores on TIMMS studies typically range between 200 and 800, out of a possible of 1000. TIMSS identifies four international benchmark levels: Low (reaching 400 pts); Intermediate (reaching 475 pts); High (reaching 550 pts); and Advanced (reaching 625 pts). These benchmark levels describe what students know and can do in mathematics (Gonzales, et al., 2004; TIMSS Website).

The results of TIMSS consecutively in 1995, 1999, and 2003 indicate that the U.S. students' achievements in mathematics are not world class. The disheartening results of these studies have led to major stories in the Wall Street Journal, the New York Times, U.S. Times, and other leading national newspapers. The Wall Street Journal, for example, painted this picture with the headlines "*Economic Time Bomb: U.S. Teens Are Among Worst at Math*" on December 7, 2004.

Table 2 shows that in 1995 and 2003, there was no change in the TIMSS results in the U.S. fourth-grade students' average score of 518. The U.S. rank, however, went down from 6th to 12th in these eight years. Note that there was no TIMSS for fourth-graders in 1999. For further details, see Gonzales, et al., (2004) and Martin, et al., (2004).

Table 2: *TIMSS Av Scale Scores of Fourth-Graders in U.S. vs. Other Countries*

Country (International Average)	1995 (496)	2003 (495)		Country (International Average)	1995 (496)	2003 (495)
Singapore	*590 (1)*	*594 (1)*		**United States**	**518 (6)**	**518 (12)**
Hong Kong SAR	*557 (3)*	*575(2)*		Cyprus	475	510
Japan	*567 (2)*	*565 (3)*		Moldova	-	504
Chinese Taipei	-	564(4)		Italy	-	503
Belgium-Flemish	-	551 (5)		Australia	495	499
Netherlands	*549 (4)*	*540 (6)*		New Zealand	469	493
Latvia- LSS	*499*	*536 (7)*		Scotland	493	490
Lithuania	-	*534 (8)*		Slovenia	462	479
Russian Federation	-	532 (9)		Armenia	-	456
England	*484*	531 (10)		Norway	476	451
Hungry	*521 (5)*	529 (11)		Iran	387	389
United States	**518 (6)**	**518 (12)**		Philippines	-	358

SOURCE: TIMSS Website

It is evident from Table 3 that the U.S. eighth-graders in TIMSS 2003 improved in their average mathematics performance over the eight-year period between 1995 and 2003. In 1995, U.S. eighth-graders ranked 17th with an average score of 492. In 2003, their rank improved to 15th with an average score of 504 far exceeding the international average of 467. For further details, see Gonzales, et al., (2004) and Martin, et al., (2004).

Table 3: *TIMSS Average Scale Scores of Eighth-Graders in U.S. vs. Other Countries*

Country (International Average)	1995 (519) (Rank)	1999 (521) (Rank)	2003 (467) (Rank)		Country (International Average)	1995 (519)	1999 (521)	2003 (467)
Singapore	609 (1)	604 (1)	605 (1)		Scotland	493	-	498
Korea, Republic of	581	587 (2)	589 (2)		Israel	-	466	496
Hong Kong	569	582 (4)	586 (3)		New Zealand	501	491	494
Chinese Taipei	-	585 (3)	585 (4)		Slovenia	494	-	493
Japan	581	579 (5)	570 (5)		Italy	-	479	484
Belgium –Flemish	550	558 (6)	537 (6)		**Bulgaria**	**527**	**511 (15)**	476
Netherlands	529	540 (7)	536 (7)		Romania	474	472	475
Estonia	-	-	531 (8)		Norway	498	-	461
Hungary	527	532 (9)	529 (9)		Moldova	-	469	460
Malaysia	-	519 (14)	508 (10)		Cyprus	468	476	459
Russian Federation	524	526 (11)	508 (11)		Macedonia	-	447	435
Slovak Republic	534	534 (8)	508 (12)		Jordan	-	428	424
Latvia-LSS	488	505 (16)	505 (13)		Iran	418	422	411
Australia	509	525 (12)	505 (14)		Indonesia	-	403	411
United States	**492 (17)**	**502 (17)**	**504 (15)**		Tunisia	-	448	410
Canada	**521**	**531 (10)**	-		Chile	-	392	387
Czech	**546**	**520 (13)**	-		Philippines	-	345	378
Lithuania	472	482	502		South Africa	-	275	264
Sweden	540	-	499					

SOURCE: TIMSS Website

Several studies, videos and books which analyze the U.S. results in their international setting discuss in detail the possible reasons for this sub-optimal performance and its consequences for U.S. mathematics education (Lane, 1996; Schmidt, et al., 1998; Kaiser, et al. 1999; NCES, 2000; Hodges, et al., 2001; Ginsburg, et al., 2004). These studies conclude that there is no single coherent vision which dominates how students practice mathematics in the U.S. These studies also suggest that the reasons for the low mathematics performance amongst American students include: curricula that lack focus and intellectual challenges; a lack of coherence across the topics in mathematics frameworks; mathematics textbooks with low standards and lack of focus; lack of competent mathematics teachers; a lack of motivation and positive attitude amongst students; and a lack of parental support.

3. COMPARISON OF MATHEMATICS EDUCATION IN THE U.S. AND SINGAPORE

A comparison of the TIMSS results in the U.S. and Singapore reveals a significant difference in the performance of students in these two nations. In fact, their performance differences lie in deep-rooted complex aspects of teaching, learning processes (such as thinking skills and heuristics), certain special skills (such as estimation, approximation, mental calculation, communication, arithmetic and algebraic manipulation), mathematics curricula, textbooks, student attitudes, culture, and parental support.

3.1 Students' Performance Differences

Table 4 illustrates that about 35% of the American fourth-graders in 2003 reached the "High" benchmark level as compared to 73% of their Singaporean counterparts. Moreover, during the period from 1995 to 2003, the U.S. fourth-graders' average score reaching the "High" benchmark fell down by 2% (from 37% to 35%), while their counterparts in Singapore went up by 3% (from 70% to 73%). On the other hand, the U.S. fourth-graders' average score reaching the "Advanced" benchmark also dropped by 2% (from 9% in 1995 to 7% in 2003); while their Singapore's counterparts remained at 38%.

Table 4: *Percentage of Fourth-Graders Reaching International Benchmarks*

	Low (400)		Intermediate (475)		High (550)		Advanced (625)	
	1995	2003	1995	2003	1995	2003	1995	2003
United States	92 %	93 %	71 %	72 %	37 %	35 %	9 %	7 %
Singapore	96 %	97 %	89 %	91 %	70 %	73 %	38 %	38 %
International Av	85 %	88 %	63 %	69 %	33 %	36 %	10 %	10 %

SOURCE: TIMSS Website

Table 5 reveals that in 2003 about one-fourth (29%) of 8th graders in the U.S. reached the "High" benchmark as compared to about three-fourth (77%) of their counterparts in Singapore. This table further demonstrates that in TIMSS 2003, only about 7% of 8th graders in the U.S. reached the "Advanced" benchmark compared to about 44% of their counterparts in Singapore. It is a matter of concern that about 10% of U.S. eighth graders in 2003 could not reach the "Low" benchmark, that is, these students do not have basic mathematical knowledge such as the understanding of whole numbers and how to do simple computations with them.

A comparison of Table 4 and Table 5 demonstrate that as 4th graders in 1995 progressed to 8th grade in 1999, the mathematics achievements of American students fell but the achievements of their Singaporean counterparts went up. This fact is further illustrated in Figure 1 for students reaching "high" benchmark. In fact, if this trend continues the U.S. universities might find it increasingly hard to get sufficient number of American students for their challenging programs in mathematics and science.

Table 5: *Percentage of Eighth-Graders Reaching International Benchmarks*

	Low (400)			Intermediate (475)			High (550)			Advanced (625)		
	1995	1999	2003	1995	1999	2003	1995	1999	2003	1995	1999	2003
United States	86%	87%	90%	61%	62%	64%	26%	30%	29%	4%	7%	7%
Singapore	100%	99%	99%	98%	94%	93%	84%	77%	77%	40%	42%	44%
International Av	89%	80%	80%	69%	57%	56%	37%	31%	28%	11%	10%	8%

SOURCE: TIMSS Website

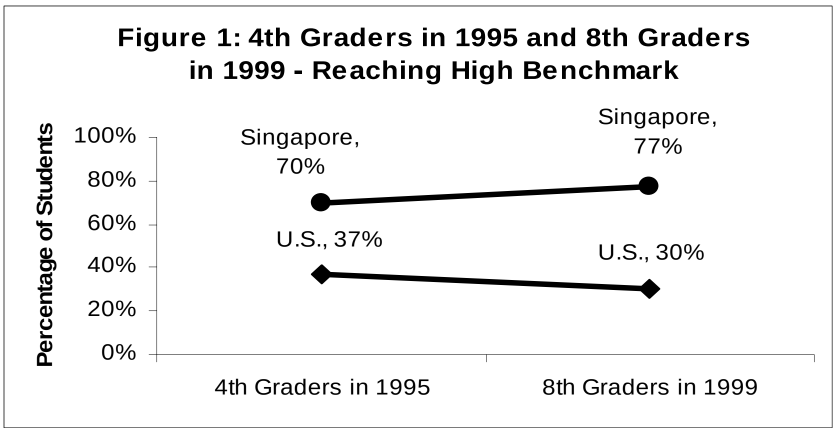


Table 6: *Average Scale Score Achievement by Gender on TIMSS 2003*

	Grade 4		Grade 8		Who is better in math abilities?
	Girls	Boys	Girls	Boys	
United States	502	507	514	522	Boys better
Singapore	611	601	599	590	Girls better
International Av	467	466	495	496	Almost same

SOURCE: TIMSS Website

We discover from Table 6 that there are interesting differences in mathematical abilities amongst boys and girls in the U.S. and Singapore. In the U.S., the mathematical abilities of boys are significantly better than that of girls. In Singapore, however, the girls outperform boys in mathematics.

Table 7 identifies that the U.S. students' mathematics achievements on TIMSS are significantly lower in all five content areas listed in Column 1. In particular, Table 7 also exhibits that a majority of the American students are weak in Measurement, Geometry and Algebra. Although the American students' average in these content areas has significantly improved in the last five years, it is still close to the international average except 'Data' analysis. On the other hand, Singapore students' average is about 25% higher than the international average.

Table 7: *Eighth-graders: % Correct Items on TIMSS*

	United States		Singapore		International Average	
Content area	1999	2003	1999	2003	1999	2003
Number	50 %	54 %	80 %	78%	50 %	48 %
Measurement	40 %	42 %	76 %	74%	44 %	42 %
Geometry	44 %	45 %	73 %	71%	51 %	50 %
Data	68 %	72 %	81 %	79%	62 %	62 %
Algebra	47 %	50 %	69 %	69%	50 %	51 %
Average	50 %	51 %	76 %	74%	51%	51%

SOURCE: TIMSS Website

Tables 4 to 7 and Figure 1 also reveal that there are significant differences in student performances in these two nations. Recent studies indicate that the treatment of a particular topic in any content area (listed in Column 1, Table 7) in an American public school may be insufficiently extended, treated in insufficient depth, inadequately consolidated, or assessed without due attention to content validity (Macnab, 2000; NCES, 2000; Ginsburg, et al. 2005). These studies also show that there are significant gaps between the intended curriculum (set by the school district), the implemented curriculum (taught by the teacher), and the achieved curriculum (learned by students).

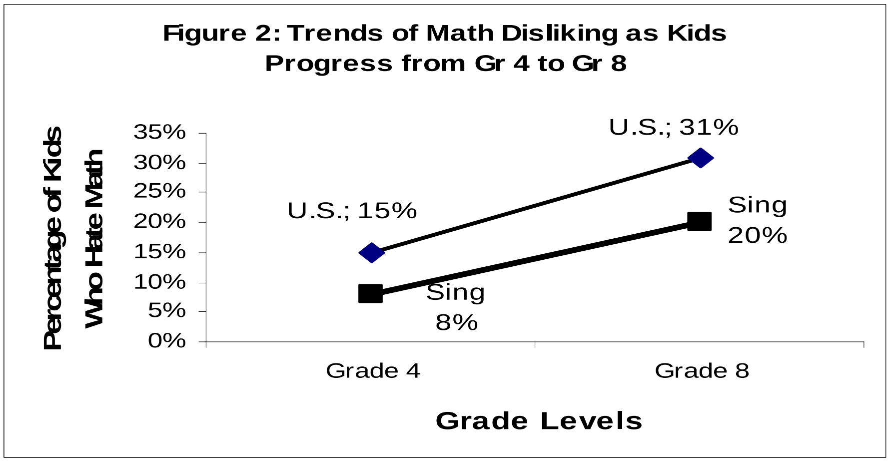
3.2 Effect of Mathematics Anxiety on Students' Performance

Several research studies have shown that the dislike of, or anxiety towards mathematics has a negative effect on mathematics performance. Table 8 reveals that many students develop an increasing dislike towards mathematics as they progress from grade 4 to grade 8. This increasing trend becomes more evident from Figure 2 which shows trends when 4^{th} grades in 1995 progressed to 8^{th} grades in 1999. Although this trend is universal, Singaporean students' dislike for mathematics is much lower than their counterparts in the U.S. These results suggest that in order to develop a positive attitude towards learning mathematics, children need to be shown from an early age that mathematics can be fun.

Table 8: *Students who dislike Mathematics on TIMSS*

	1995		1999		2003	
	Gr 4	Gr 8	Gr 4	Gr 8	Gr 4	Gr 8
United States	15%	30%	No study	31%	20%	40%
Singapore	8%	22%	No study	20%	15%	25%
International average	16%	37%	No study	31%	22%	40%

Source: TIMSS Website



3.3 Comparison of Mathematics Frameworks/ Standards

Table 9 provides highlights of mathematics frameworks in the U.S. and Singapore. The key difference is that while the U.S. has no official national mathematics framework, Singapore has a grade-by-grade national framework, which focuses on and emphasizes high-level cognitive processes. Each State in the U.S. and even many of the cities and school districts within each state, have their own mathematics framework or curriculum. While some states such as Virginia and California do have focused and grade-specific curricula, Ginsburg et al. (2005) observed that the 'National Council of Teachers of Mathematics' (NCTM) framework (NCTM, 2000), while emphasizing higher order 21st century skills in a visionary way, lacks the logical mathematical structure of Singapore's framework. They also discovered that the NCTM framework identifies content only within broad grade bands (e.g., K-2, 3-5) and only in general terms, thus providing inadequate content guidance to educators. Nevertheless, because of the 'No Child Left Behind' (NCLB) Act (U.S. Congress, 2002), grade-by-grade assessments are now required and many states are shifting to grade-by-grade content standards.

The essential finding of the K-12 'State of the State Mathematics Standards 2005' (Klein et al., 2005) confirms that an overwhelming majority of states in the U.S. today have inadequate mathematics standards. The national average grade is a "high D". Only six states earned the "honors" grades of 'A 'or 'B'. California, Indiana, and Massachusetts received an 'A' grade and are considered to have first-class mathematics standards, worthy of emulation. Alabama, Georgia, and New Mexico received a 'B' grade, while 15 states received Cs, 18 received Ds, and 11 states received Fs. For the complete report, see Klein et al. (2005).

Table 9: *Mathematics Frameworks*

	United States	Singapore
1.	Regional and local, mostly unfocused, repetitive, low-level knowledge and skills.	Federal, focused, non-repetitive (except for slow learners), emphasize on high level cognitive processes.
2.	NCTM framework (not a national framework) identifies content only within broad grade bands and only in general terms; some of the states provide grade-by-grade, focused and specific framework.	Framework covers grade-to-grade, specific and challenging following a spiral organization.

SOURCE: TIMSS Website

3.4 Supports for Slower Mathematics Students

Table 10 highlights the differences in support for slower mathematics students in the U.S. and in Singapore. Unlike Singapore, most state and NCTM curricula in the U.S. do not provide any alternative framework for slower mathematics students. Certain U.S. school districts such as 'San Jose Unified' and 'Los Angeles Unified' in California have created continuation schools, which may be viewed as models for alternative education. However, in most of the states as observed in the TIMSS data, slow mathematics students in the U.S. are often tracked into slower and watered down mathematics courses where they are generally not taught the required mathematics materials. In fact, it was revealed by Schmidt (1998) that in over three-fourths of the American schools, eighth graders often take different mathematics courses – regular or 'general' math, remedial math, enriched math, prealgebra and algebra.

Table 10: *Support for the Slower Mathematics Students*

	United States	Singapore
1.	No alternative math frameworks; unofficial tracking often exists but the students rarely learn all the required mathematics content.	Alternative math framework at a slower pace and with some repetition; students generally learn all the required math content.
2.	Teacher aids for extra help.	Specially trained teachers for extra help.
3.	NCLB addresses the needs of failing schools, but not of failing students.	Ministry of Education addresses the needs of all schools and students.
4.	NCLB judges schools based on a measure of "Adequate Yearly Progress" (ADY).	Ministry of Education rewards schools based on a measure of each school's value-added contribution to student achievement.

SOURCES: Ginsburg, et al. 2005; TIMSS Website

3.5 Comparison of Mathematics Textbooks

A world-class K-8 mathematics textbook should provide rich mathematical content that is aligned with the required standards and framework. It should have extensive problem sets that include routine and non-routine problems, and should use sound pedagogical approaches (McKnight 1987; Tyson, 1989; AAAS, 2000). In view of these criteria, Singapore mathematics texts are considered world-class. Singaporean textbooks provide a deep understanding of mathematical concepts and skills and use a spiral approach without unnecessary repetition. These texts also use picture representations or real life/practical examples to explain abstract concepts. On the other hand, American mathematics textbooks are generally too long, and written to cater for about 15,000 mathematics curricula in the nation (Ginsburg et al, 2005). Table 11 summarizes a comparison of most of the traditional mathematics textbooks used in these two nations.

Table 11: *Mathematics Textbooks*

	United States	Singapore
1.	Built for enhancing mechanical ability to apply mathematics concepts.	Built for deep understanding of mathematics concepts.
2.	Simple routine problems.	Multi-step challenging problems.
3.	Beautiful colored pictures, but lack of visual representations to guide conceptual understanding.	Illustrations range from a concrete to pictorial to abstract approach.
4.	Lack of focus since they are written for several state frameworks.	Focused and follows national framework.
5.	Spiral approach, but with a lot of repetition.	Spiral approach, with a little repetition.
6.	More topics, a lot of review but less depth (700 pages average).	Less topics, more coverage (between 250- 300 pages average).

SOURCES: TIMSS Website; Tyson-Bernstein, 1988, Tyson, et al. 1989; Ginsburg, et al. 2005

3.6 Teachers' Qualifications and Professional Development

"*About one-third of practicing mathematics teachers in the U.S. has neither a major nor a minor in mathematics during their undergraduate degree. These teachers typically teach 26% of the country's mathematics students*" (Ingersoll, 1999). It was further revealed by Glenn (2000, p19) that "*more than 12% of all new teachers in the U.S. enter the classroom without any formal training; another 14% start work without meeting the teaching standards of their states*". Moreover, I've also observed in my classes that the majority of preservice teachers for early childhood and middle grade programs come in with negative attitudes towards teaching and learning mathematics. Although they may have rote knowledge of arithmetic, many preservice teachers do not have the deep conceptual understanding that they need for teaching mathematics in these grades. On the other hand, although elementary school teachers in Singapore typically have considerably less college education than their U.S. counterparts, most of them are competent and qualified to teach mathematics (Ginsburg, et. al., 2005).

Although many states have induction polices, the overall support for new teachers in the U.S. is fragmented due to a wide variation in legislation, policy, and type of support available (Wang, et al., 2003). Only about a half of the new teachers in the U.S. receive formal teacher induction programs in their first year of teaching (Choy, et al., 1998). On the other hand, Singapore provides all new teachers with induction support during their first year (MOE, 1999), which includes reduced teaching load, mentoring, and on-the-job training during the first year.

The Singapore education system has four essential elements in its continuing professional development program: (i) An annual target of 100 hours of professional development for each teacher, (ii) A modular approach to teacher training in order to upgrade each teacher's skills in various topics to varying depths, (iii) Online teaching to supplement face-to-face instruction, and (iv) Formal recognition of teachers for courses taken (MOE, 1999; Hean, 2000). In contrast, a typical professional development program in the U.S. is not as high in quality and consists of no more than a day on a specific content area (Parsad, et al., 2001). Nevertheless, there are several states and school systems in the U.S. that are providing excellent professional development programs. An example worth mentioning is that of Connecticut (Sykes, et al., 2004).

3.7 Teaching Practices and Teacher Training

Table 12 shows that there are major differences in teacher training programs, teaching strategies and teaching practices in these two nations. Singapore's basic philosophy about a teacher's knowledge can be best described by a famous Chinese proverb, "*A teacher needs to have a bucket of water before he is able to give students a bowl of water*." Mathematics teachers therefore need a solid foundation in mathematics, with knowledge that is much deeper than what they are expected to teach.

Table 12: *Teaching Practices*

	Issue	United States	Singapore
1.	Class Time	Teachers seldom have time to go in depth because of too many topics.	Teachers have time to go into more depth.
2.	Subject knowledge of mathematics teachers	Most teachers are trained in education.	Most teachers have a strong background in mathematics.
3.	Teacher's goal	Teach students math skills.	Help students to understand mathematics concepts and skills.
4.	Using research	Only a few teachers use latest research ideas.	Most teachers widely use latest research ideas.
5.	Support and sharing	Unfocused and generally work in isolation.	Focused sessions and a lot of sharing of strategies and lesson plans.

SOURCES: Ginsburg, et al., 2005; Ahuja, 2003; TIMSS Website

4. REFLECTIONS ON SINGAPORE'S SUCCESS STORY

Let us now look at some of the factors which make Singapore the topmost in K-12 mathematics education.

In the Second International Science study (SISS) in 1983-84, the performance of Singapore's 4th graders (13th among 15 nations) and 8th graders (13th among 18 nations) in mathematics was quite unsatisfactory. In 1990, the Ministry of Education of Singapore enhanced the mathematics curriculum to one that emphasized on process skills (e.g. thinking skills, heuristics), attitude development, and streaming based on student ability (MOE, 1996).

While in Singapore, I witnessed the rise of the educational system to one that was becoming superior to those of most other nations. I witnessed their unfaltering belief that a strong educational system provides the means to stay ahead of competing nations. Confucian beliefs about the role of effort and ability in achievements are developed in the kids by their parents and schools right from childhood. Good manners, good attitude, a neat appearance, and perfect attendance are emphasized in all schools. When students fail or get a poor grade, they generally attribute it to their lack of efforts. This failure creates determination in many students to work harder and to pay more attention to their academics.

Some of the key features contributing to Singapore's success include: students' high educational aspirations and positive attitudes toward mathematics, world-class facilities in all schools, safe school environments, alternative mathematics framework and special assistance for slow learners, gifted education program, excellent textbooks, and competent and dedicated mathematics teachers. One of the most important features of the Singaporean educational system is that of streaming. The basic philosophy of streaming is reflected in the Singapore Ministry of Education's mission statement: "*Every child must be encouraged to progress through the education system as far as his ability allows. Advancement must always depend on performance and merit to ensure equal opportunity for all*" (MOE, 2003). On the basis of their abilities, students from grade 5 are placed in two or three different streams. But, slow learners study the same mathematics topics as the other two streams over a longer period of time and with extra assistance from teachers. There is an alternative mathematics framework with mathematics textbooks for each grade in the slower stream and well-trained specialist mathematics teachers. Furthermore, there are several opportunities for students with varying abilities to attend night tuition classes organized by various associations and private companies.

Features contributing to Singapore's success include: a lighter workload for new teachers; the mentoring of new teachers by more experienced teachers; common teachers' rooms with individual desks to work at; well-informed and well-structured guides, worksheets and lesson plans; a lot of cooperation and sharing among teachers within schools, neighborhoods and at the national level; and the availability of manipulative, software and computers. Most Singaporean teachers make an effort to attend meetings, workshops, and conferences during the year. They share and hear about the successes and failures of other teachers. Thus there is a lot of professional interaction. Teachers generally incorporate a variety of methods in teaching mathematics such as assigning theme-based projects and using diagrams and models. Most teachers in elementary and middle grade schools make mathematics interesting by manipulating objects using various software (such as Graph Club, Graphmatica, TesselMania, and Geometer's Sketchpad), and incorporating a variety of research-based teaching techniques in their lessons. Most teachers also focus on active problem solving during class time.

Key features of Singapore's educational system include: common national examinations at the end of grade 6, grade 10, and grade 12; a broad-based school ranking system to keep up standard and competition (MOE, 2004); a national curriculum; textbooks and pedagogical guides; and a lot of investment in education. Most importantly, the taught mathematics curriculum in schools is generally more than the intended mathematics curriculum (set at national level).

The National Institute of Education (NIE) of the Nanyang Technological University (NTU) in Singapore is a world-class teacher training institute where academics and educators work together to help the Ministry of Education in improving mathematics education in Singapore. The important thing about NIE's Mathematics department is that the mathematicians and mathematics educators work together: they belong to the same department, they have the same goals and ideals, and they work together on students' programs. Moreover, almost all professors of NIE, whether in pedagogy or content areas, supervise student teaching in schools. NIE has world-class professors, salary scales, facilities, academic programs, and excellent conceptual frameworks. Special features of NIE's teacher training programs include: full salary, fee waiver, and full service benefits for student-teachers throughout their training period. However, they are required to sign a bond to teach for the next 3 to 4 years. All prospective teachers for elementary schools are trained in six main areas of study: Educational Studies, Curriculum Studies, Curriculum Content, Academic Subjects, Practicum, and Language Enrichment and Academic Discourse. For more information, one may refer to (NIE Website).

Most Singaporean school students (about 80% as per TIMSS Website) have the desire to work hard in mathematics. They spend more than one hour a day on mathematics outside school time (TIMSS Website).

5. CREATING WORLD CLASS HIGH QUALITY K-12 MATHEMATICS EDUCATION IN U.S.

How do we succeed in creating the world-class mathematics education in the U.S. that was proposed by the Governors Conference in September 1989 and set as the fifth goal by the U.S. Department of Education (U.S. Department of Education, 1989)? Surely, the U.S. or any other country cannot merely emulate the practices of Singapore or other top performing nations such as Japan, Korea, Hong Kong SAR, and Belgium. Each country's education practices go hand in hand with its culture and society. That being said, the U.S. and its educational agencies do need to reconsider their own practices and find alternative ways of applying the knowledge of top performing nations in light of their own society and context. Singapore's success story tells us that if any nation has the will and determination, such a goal is not difficult to achieve.

The U.S. has the resources to create a world-class mathematics education system. The NCLB Act clearly shows federal commitment toward improving mathematics education in the nation. Such a commitment is also evident from what President George W. Bush delivered in his '2006 State of the Union Address' (Bush, 2006); the following are the relevant excerpts from his address:

> *"…To keep America competitive, one commitment is necessary above all: we must continue to lead the world in human talent and creativity. …We need to encourage children to take more mathematics and science, and to make sure those courses are rigorous enough to compete with other nations. We've made good start in the early grades with the No Child Left Behind Act, which is raising standards and lifting test scores across our country. Tonight I propose to train 70,000 high school teachers to lead advanced-placement courses in math and science, bring 30,000 math and science professionals to teach in classrooms, and give early help to students who struggle with math, so they have a better chance at good, high-wage jobs…"* (Bush, 2006).

The U.S. has thousands of towns and cities, many of them smaller or about the same size as Singapore. Most of these towns and cities are free to design their own programs, although there is already some level of federal or state control over school districts because of the NCLB Act. If each school district or local government starts by raising its children to be the best in the world in mathematics, the whole nation can become number one in the world in mathematics education. In the words of President G. Bush, "…*If we insure that America's children succeed in life, they will ensure that America succeeds in the world…"* (Bush, 2006). Moreover, this is an achievable goal, since it was found by researchers (Snipes, et. al., 2002) that smaller school districts could reap significant academic benefits by ensuring that students learn high levels of uniform content, as students do in Singapore. We have some examples of school agencies in the U.S. which have created world-class mathematics education systems that are very similar to Singapore's educational system. Examples include Naperville School District #203 (IL), First in the World Consort (IL), and Montgomery County (MD). All these school districts achieved above the international average in TIMSS with scores comparable to any of the industrialized or G8 nations (TIMSS Website).

5.1 Create a World-Class Mathematics Framework and Curriculum

A world-class mathematics framework always provides a clear message for teachers, students, and parents. For example, the Introduction to New Mathematics Content for California Public Schools states:

> "*These standards are based on the premise that all students are capable of learning rigorous mathematics and learning it well, and all are capable of learning far more than is currently expected. Proficiency in mathematics is not an innate characteristic; it is achieved through persistence, effort, and practice on the part of students and rigorous and effective instruction on the part of the teachers*" (CDE, 1999).

The essence of a worthwhile vision for mathematics education should be the development of mathematical ability and expertise. Mastery of mathematical ideas, concepts, processes, and the ability to put them into practice, is what society quite reasonably expects of mathematics education (Macnab, 2000). In order to make students flexible and competent problem solvers so as to meet the demand of the 21st century competitive world, any mathematics framework should be centered on mathematical problem solving. Such a framework should place an emphasis on all those concepts, computational skills, and thinking processes which are needed for a child to become a flexible and competent mathematical problem solver. Although several state standards and NCTM standard include many great ideas, there is a need to consider integrating state or NCTM-based mathematics standards with grade-by-grade concepts (such as numerical, geometrical, algebraic and statistical), processes (e.g. thinking skills and heuristics) and core mathematics skills (e.g. estimation and approximation, mental calculation, communication, arithmetic and algebraic manipulation). Such a framework should also emphasize developing attitudes such as appreciation, interest, confidence, and perseverance, as well as metacognition, i.e. monitoring one's own thinking.

TIMSS data suggests that most U.S. mathematics curricula need to place greater emphasis on areas such as: attitudes towards learning mathematics, problem solving and high-level thinking skills, measurement, estimation and mental mathematics, geometric shapes, perimeter, area and volume, congruence, similarity, vectors, geometric transformations, and three-dimensional geometry. Most importantly, evidences reviewed in previous sections suggest that any mathematics curriculum should also include topics to be studied, the depth at a particular stage, the balance and relationship between knowledge, understanding and investigation, and the expected achievement levels at various ages. Also, see (Macnab, 2000). Additionally, there are the following ten suggestions for states and school districts to consider:

1. Design a mathematics curriculum which ensures that teachers teach to mastery so that there is no need for re-teaching (except for a short review) of the same content in the subsequent grade levels.
2. Consider the spiral approach but without excessive repetition in successive years.
3. Focus on a few topics at each grade level, teach those topics in greater depth, and help students master challenging mathematics.
4. Focus on mathematics content, mental mathematics skills, estimation, and multi-step problem solving.
5. Take arithmetic instruction seriously in the elementary grades and ensure that it is mastered before a student proceeds to high school (Klein, et al. 2005).
6. Emphasize reasoning and mathematical problem solving at every level of mathematics teaching.
7. Use technology as a tool that is a means to the end, rather than an end in itself.
8. Have integrated/cohesive system to minimize gaps between (i) Intended Curriculum (set by state, city, or school district), (ii) Implemented curriculum (by the respective school district or school), (iii) Taught curriculum (by the teachers), and (iv) Attained Curriculum (assessed by external examinations).
9. Develop an official 'Alternate Mathematics Framework' for slow learners. Such a framework will ensure that these students are taught all the required material in less depth but at a slower pace within an extended period of time. Moreover, research shows that children with mathematical learning disabilities do much better in more structural learning environments (Darch, 1984, Miller, et al., 1997).
10. Develop special mathematics programs for high-ability and gifted students in mathematics jointly with the universities.

5.2 Produce World-Class Mathematics Textbooks

A world-class mathematics curriculum cannot create world-class mathematics education unless there are world-class mathematics textbooks to supplement it. Generally, textbooks in the U.S.

are written with an aim to serve all categories of students in thousands of school districts. The school districts or states may consider asking the writers of grade K-12 mathematics textbooks to follow certain guidelines, such as:

1. Textbooks should build a deep understanding of mathematical concepts, contain concrete illustrations (wherever necessary), provide multi-step problems, use sound pedagogical approaches, and also contain mathematically rich problem-based examples and exercises and should have challenging mathematics assessments.
2. Simplify and reduce the size of textbooks considerably by reducing the number of unrelated topics and avoiding repetitive materials from previous grade levels.
3. Textbooks should have strong content development and use the model approach in explaining concepts, wherever possible.
4. There should be special mathematics textbooks and workbooks for slow learners, based on an alternate mathematics framework.

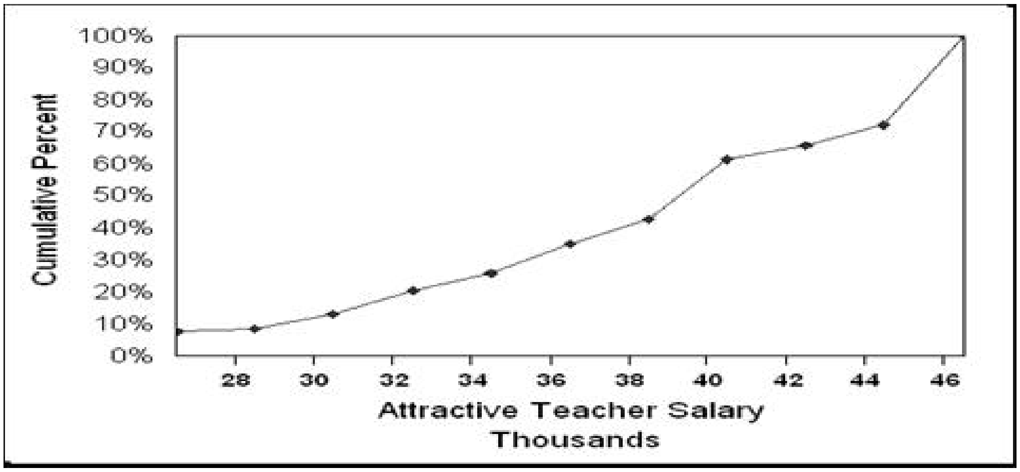
5.3 Recognize and Remove Barriers which Prevent Female Students from Learning Mathematics

As observed in Table 6, male students in the U.S. do better in mathematics than the female students. On the other hand, female students in Singapore are better in mathematics achievements than their male counterparts (Table 6). There is, in fact, a great deal of evidence to suggest that gender differences in mathematics achievement are not biologically or genetically based. It has been suggested that the decline of female achievements is the result of a strong pattern of socialization to mathematics success or failure rather than to gender differences in innate ability (Callahan et al., 1984). Since the goal of mathematics education is to promote students' mathematics achievement, and since gender equity is, in general, a societal goal, it is crucial to recognize and remove the barriers that prevent females from learning mathematics. Most importantly, we should (i) change parents' and teachers' attitudes towards female learning styles, and (ii) bring concrete changes in teaching methods and curricula, for example cooperative learning that promotes collegiality between male and female students (see Schwartz, et al.,1992).

5.4 Make Mathematics Teaching A World-Class and Attractive Profession

The Glenn Commission (Glenn, 2000) observed that American society "*frequently refuses to recognize the professional status of teachers, ranking them below doctors, lawyers, and clergy*". Gerstner (2004) also pointed out that "*the only way to ensure that we remain a world economic power is by elevating our public schools, particularly the teachers who lead them, to the higher tiers of American society*". In the same article, he further suggested that "*Elevating public schools to that level means that we should consider making the teaching profession world-class and attractive by offering salaries and benefits according to the qualifications and experience comparable to other professionals*".

Figure 3: *Cumulative Percentage of Talented College Sophomore and Junior Respondents Who Would Consider A Teaching Career* (SOURCE: *Milanowski, 2003)*



Milanowski (2003) through a research survey and Figure 3 discovered that *"mathematics, science, and technology majors see K-12 teaching as a low paid field, and that many would consider it if it paid substantially more than their current occupational choice"*. In addition to attracting, rewarding, and retaining high quality mathematics teachers, federal and state governments ought to consider having specialized mathematics teachers from Grade 4 onwards in all the public schools.

5.5 Provide World-Class Professional Development for All Mathematics Teachers

In order to create a world class mathematics education system, it is necessary to provide ongoing world-class professional development programs for all mathematics teachers. Incidentally, the federal NCLB Accountability Act requires that all in-service teachers who teach mathematics should be highly competent on content-based mathematics. In this regard, consider the following suggestions:

1. Instead of the current system of short-term workshops, develop professional development programs which may offer credit or non-credit courses as a part of continuing education. States may follow Connecticut's style of a comprehensive 'professional model' for training teachers (Sykes et al., 2004). Alternatively, those teachers who are not highly qualified to teach mathematics should be encouraged to take up content based coursework in mathematics during weekends and long vacations.
2. School districts need to provide frequent in-class support from expert mathematics teachers and time and opportunities for mathematics teachers to meet together on a regular basis to discuss their model lessons; to discuss teaching strategies; to analyze and evaluate their teaching; to talk about their students' learning; and to discuss the use of new technologies in teaching mathematics.
3. Universities should offer specially designed content-based course work or programs in mathematics during summer vacations, with financial help from federal and state governments. Some of the universities have recently been progressing in this direction.

4. Encourage and reward in-service teachers who spend a considerable amount of time and effort, and show good improvement in professional training or take up content-based university courses in mathematics.
5. Provide and encourage mathematics teachers to take special training or courses for teaching mathematics to slow learners.

5.6 Provide World-Class Mathematics Education for Prospective Teachers

"*High quality teaching requires that teachers have a deep knowledge of subject matters*" (Glenn, 2000, p22). It is further observed that teachers' cognitive ability, content knowledge, and professional training are important in teacher quality and student achievement (Whitehurst, 2002). This fact is supported by NCLB Act which requires that only highly qualified teachers deliver instructions (U.S. Congress, 2002).

There is evidence of a vicious cycle in which too many prospective teachers enter college with an insufficient understanding of school mathematics, with little college instruction focused on the mathematics they will teach, and with inadequate preparation to enter their classrooms to teach mathematics to the following generation of students (Ball, 1999; CBMS, 2001). This is why a number of mathematicians and mathematics education researchers have recognized the special nature of the mathematical knowledge needed for K-12 teaching and its implication for the mathematical preparation of teachers (Ma, 1999; CBMS, 2001). In this regard, the following suggestions are offered:

1. Attract talented mathematics students for prospective education majors by offering them scholarships and/or full fee waiver.
2. Attract talented unemployed graduates in engineering, computer science, and business by offering them scholarships and by providing them one-year post-graduate teacher training programs.
3. Provide high quality mathematics education courses that develop a deep understanding of the mathematics content they will teach.

5.7 Promote Cooperation Between Mathematicians and Mathematics Educators

"Most mathematicians and mathematics educators in the U.S. live in different worlds: they have different cultures, different standards of rigor, and different languages to talk about mathematics learning" (Cuoco, 2003). Indeed, a Google search on "math war" will turn up thousands of newspaper articles and websites arguing for or against various approaches to teaching mathematics (Jackson, 1997; Cuoco, 2003, p781). Mathematicians and mathematics educators, instead of pursuing "math wars" as seen in the 21st century, should commit to shared accountability and responsibility to provide world-class mathematics education to prospective teachers.

5.8 Promote Parental Involvement in Creating World-Class Mathematics Education

Parental involvement can greatly help a school in providing world-class mathematics education. Every school should promote partnerships that will enhance parental involvement and participation in promoting the social, emotional, academic growth, and in particular, mathematics education of children. Elementary school years are important for fostering constructive learning habits that are reinforced in the home and are essential to life as an adult

(Duke 1986). It is therefore imperative that parents and, in fact, all other adults who play an important role in their children's home lives, help their children in developing self-discipline, perseverance, and a positive attitude towards learning and hard work. They should also help their children appreciate and value that mathematics is an important subject for their high school and college education, and also for many careers. In this regard, the parents or guardians of K-12 students should also be encouraged to:

1. Take an active interest in their children's mathematics education,
2. Make sure that their children do their mathematics homework consistently and prepare well in advance for their mathematics tests, projects, and examinations,
3. Ensure that schools do a good job in teaching mathematics, and
4. Understand and value the importance of mathematics in their children's education.

5.9 Other Suggestions for Federal and State Governments

It is still not too late to make all possible efforts to make the U.S. number one in school mathematics education in the world. In this regard, federal and state governments may also consider the following ten suggestions:

1. Consider improving the NCLB Accountability Act by holding schools, teachers, students, and parents accountable for their students' performances.
2. Replace the authors of weak standard documents with people who thoroughly understand mathematics, including university professors from mathematics departments (Klein, et al, 2005). In this regard, California is making headway by encouraging and involving university mathematicians in writing mathematics standards.
3. Consider borrowing a complete set of high quality mathematics standard from a top-scoring state (Klein, et al, 2005).
4. Reward schools that demonstrate students' academic growth measured by the difference in the students' entry level abilities and their abilities upon graduation. For example, see recently revised broad-based school ranking system in Singapore (MOE 2004).
5. Ensure world-class facilities in every classroom, such as a PC, projector, Internet, manipulative, concrete objects and others.
6. Ensure that weaker students in mathematics are given more time and extra help, after school hours, in small groups by specially trained and competent mathematics teachers.
7. Re-educate parents, administrators and the general public to understand and support reforms in mathematics education.
8. Popularize mathematics by making it fun and implementing programs such as 'Mathracy', 'Numeracy', 'Compute to your kids', 'Have fun in math with your kids' etc.
9. Provide all possible help to fix up financial crises in poor school districts that prevent them from advancing mathematics to worldwide standards.
10. Consider ways to invest heavily on education for at least the next ten years.

6. CONCLUSION

The United States is world-class in many areas. It is critical for the nation to become world-class in K-12 mathematics education as well. The consequences of supporting this vision include great economic prosperity and an overall higher quality of life for all Americans. Some states and school districts have been striving hard to achieve world-class mathematics education in their schools, for example, California, Indiana, and Massachusetts which received 'A' grades for having first-rate mathematics standards (Klein, et al., 2005). The United States can look forward to a top-notch K-12 mathematics program, and possibly succeed in achieving the goals set forth by NCLB if all the states in the country successfully develop world-class standards in mathematics education, align all other key educational policies (such as. salaries, teacher preparation and development, accountability, textbooks, graduation requirements etc) with those standards, and if their schools and teachers succeed in instructing students in the skills and content specified in those standards (also see Klein et al., 2005). Based on Glenn commission (Glenn, 2000), our motto should be "World-Class High Quality Mathematics Education for All K-12 American students, Without Any Delay! And –Without Any Excuses!"

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