Mathworks: An innovative approach to systemic change in mathematics education

"Never doubt that a small group of thoughtful, committed citizens can change the world. Indeed, it's the only thing that ever has." Margaret Mead

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A Look at the International Perspective

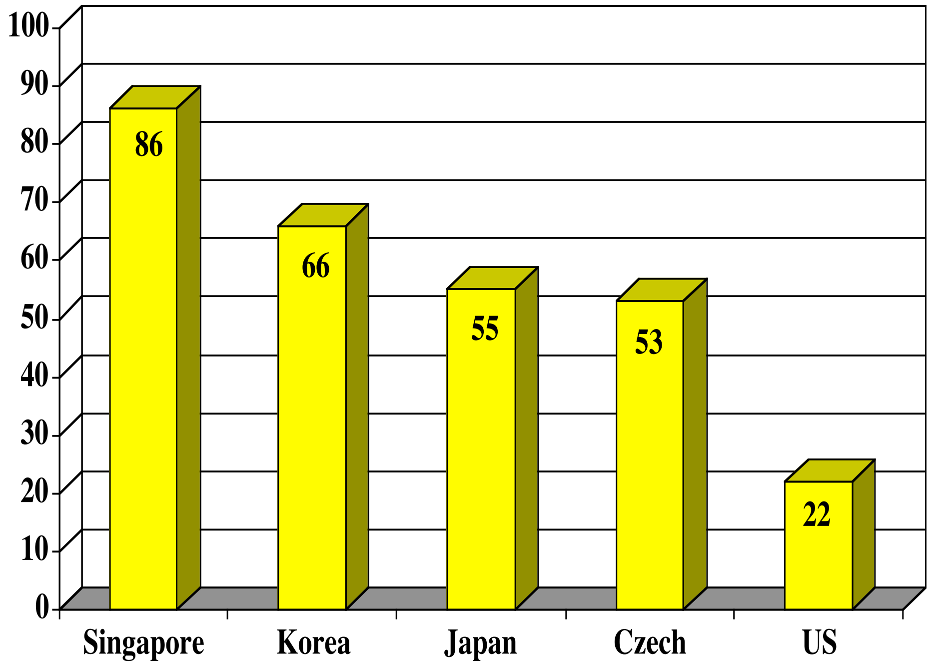
From an international viewpoint, researchers have long sought extensive data on student performance in mathematics at all levels of education, and how and if student performance varies from country to country. These researchers believe that it is not enough simply to compare any one country's students to each other and suggest international comparisons as a less myopic perspective. For instance, Cai (2001) compared the performance of American and Chinese sixth grade students on four types of mathematical tasks and concluded that American students needed to concentrate on developing symbolic and algebraic thinking.

For an even more expansive international perspective, Mullis (1999) pointed to the 1995 Third International Mathematics and Science Study (TIMSS) as a way to compare the mathematics performance of US students to students from other countries. According to Mullis, this study covered 42 countries, 500 schools, and 33,000 students. Three grade levels of mathematics and science from the US were examined: fourth, eighth, and twelfth. The US fourth grade students were above the average in both mathematics and science, the eighth grade students were above the average in science and below the average in mathematics, and the twelfth grade students were below the average in both. This TIMMS study provided the first international benchmarks in mathematics and science that could be used as a foundation for research in educational trends and policies and as a means to monitor and compare student achievement in these disciplines worldwide.

In 1997, a report entitled *Attaining excellence: A TIMSS resource kit* (cited in Mullis, 1999) was formulated for educators interested in using the TIMSS data to improve teaching and learning. Mullis' work incorporated this 1997 report focusing on it and the National Assessment of Educational Progress (NAEP) module. One section of Mullis' report concentrated on the NAEP and the TIMSS eighth grade mathematics assessments and considered how the test questions were distributed across the content areas of algebra and geometry. The following is a typical eighth grade level problem taken from the 1995 TIMSS study.

> The length of a rectangle is 6 cm and its perimeter is 16 cm. What is the area of the rectangle in square centimeters?
>
> Figure 1 shows US students' scores on this problem compared to those of four other countries.

Figure 1
Percent of Correct Responses of US Students to Typical Eighth Grade Level Problem Compared to Those of Four Other Countries



Note: Data taken from TIMSS, 1995.

It is obvious from Figure 1 that only one out of five US eighth grade students answered the question correctly, while close to nine out of 10 eighth grade students from Singapore answered it correctly.

In 1999, the TIMSS study was repeated at the eighth grade level only. This time, there were 38 participating countries, and the US was slightly above the average but not in the top 15 countries in any category. There were five areas of concentration in mathematics: fractions and number sense (US above average), measurement (US below average), data representation, analysis, and probability (US above average), geometry (US not significantly different from the average), and algebra (US above average).

A Look at the National Perspective

Looking back on algebra teaching and learning in the United States over the past few decades gives reason for both hope and concern. Nationally speaking, many movements address a problem described by Carter, Ferrucci, and Yeap (2002) as students' inability to grasp fundamental principles in algebra, which then leads them to avoid algebra classes and thereby eliminate themselves from many professional opportunities and higher educational options.

Educators have known of this problem for years and have devised many possible solutions for it. Wu (2001) claimed that the study of fractions alone provides a ramp access from arithmetic to algebra. Barnard (2002) supported this idea and states, "Much time is needed practicing adding and subtracting numerical fractions." Gallardo (2002) considered the historical perspective to try to analyze how students move from arithmetic to algebra using word problems as her instructional context. Elliott, Oty, McArthur, & Clark (2001) offered their year long experimental study as proof that students who take an interdisciplinary course in algebra have slightly higher gains in critical thinking and significantly more positive attitudes when they finish the course than students who take a traditional algebra course. A different approach promoted by Broekman and Hoffmann (2002), used word problems to determine abstraction levels and to answer the question frequently posed by students: "Do we really need algebra?"

Addressing this question, Wilkins and Ma (2002) sought to determine factors that influence successful mathematics learning by examining data from the national Longitudinal Study of American Youth (LSAY), as reported by Miller, Kimmel, Hoffer, & Nelson (2000), which studied 3,116 students in the seventh grade in 1987 and followed their achievements in mathematics and science for the next six years. Wilkins and Ma concluded that "on average, the rate of growth in mathematics achievement from taking algebra was almost two and three times that of taking statistics in middle school and high school, respectively."

Dozens of programs and software companies have marketed their products as a necessary link to success in algebra: *NASA Connect* targets students in grades 6-8 but is adaptable to higher and lower grade levels (Wilkinson, 2001; NASA, 2000), *Algebra Stars* is devised for students in grades 7-9 (McMullin, 2002), *The University of Chicago School Mathematics Project is* designed for students in grades 9-12 (Thompson & Senk, 2001), *Interactive Mathematics* is constructed for pre-algebra, algebra I and II (Tassler & Fleisher, 2002), and *Mathmagic* is aimed at middle school students (Koirala & Goodwin, 2000), to name just a few.

One of the pressing algebra related issues is teacher preparation, especially as teacher preparation pertains to curriculum and pedagogy. Researchers have investigated this issue by examining: teacher content knowledge (Sherin, 2002); the impact of teachers on students' classroom explorations in mathematics (Chazan, 1999); and the relation between algebra 1A exam performance and (a) teacher education levels, (b) years of teaching experience, (c) certification for mathematics instruction, and (d) completion of pertinent in-service training courses (Larson, 2000). One collection of papers, which addressed both positive and negative aspects of mathematics and science teacher preparation, is *Promoting excellence in teacher preparation: Undergraduate reforms in mathematics and science* (Powers & Hartley, 1999). Some critical curriculum and pedagogy issues that were examined and identified by this research collection as needing reform include: (a) improving students' attitudes and performance in algebra, (b) improving content and methods courses for pre-service teachers, (c) including all students in higher level courses, and (d) revising teaching methods to enhance student learning and participation rates.

Yet another persistent problem pursued nationally by researchers (Wilkins & Ma, 2002, Smisko, Twing, & Denny, 2000; Cruse & Twing, 2000; Smith, Brooks-Gunn, & Klebanov, 1997) is the quality of the assessment rubrics and the reliability and validity of these rubrics for assessing different states, cultures, and students. One response to this national need for improved high school algebra instruction and testing occurred when 12

Southern states joined forces to create the Southern Regional Education Board to design a database of algebra exam questions that was appropriate for all students in that region (Hoff, 2001).

However, standardized assessment and quality of instruction are not the only problems related to algebra that are actively being addressed in the US. Access to algebra has long been a very thorny problem. In spite of movements like "Algebra for All" (Choike, 2000; Pugalee, 2001), which insists that at-risk students be permitted to take algebra, and reports citing that more high school students are taking advanced mathematics and science courses (More students taking tough math courses, 2000), some students are still being denied access to algebra. Masini (2001) looked at eighth grade algebra students from the 296 classrooms participating in the 1999 TIMSS and discovered stark differences between high socioeconomic status (White/Asian) and minority classrooms (Hispanic/African-Americans). The differences were attributed to tracking students, which decreases opportunities to choose learning levels and to curricular rigor, which was evident in the White/Asian classrooms but virtually absent in the minority classrooms.

Since research clearly shows that access to algebra opens doors for students to choose education and career options, as a nation we must provide this opportunity to all of our citizens equally. Educators in many states are currently addressing this issue.

A Look at Two State Perspectives: Massachusetts and Texas

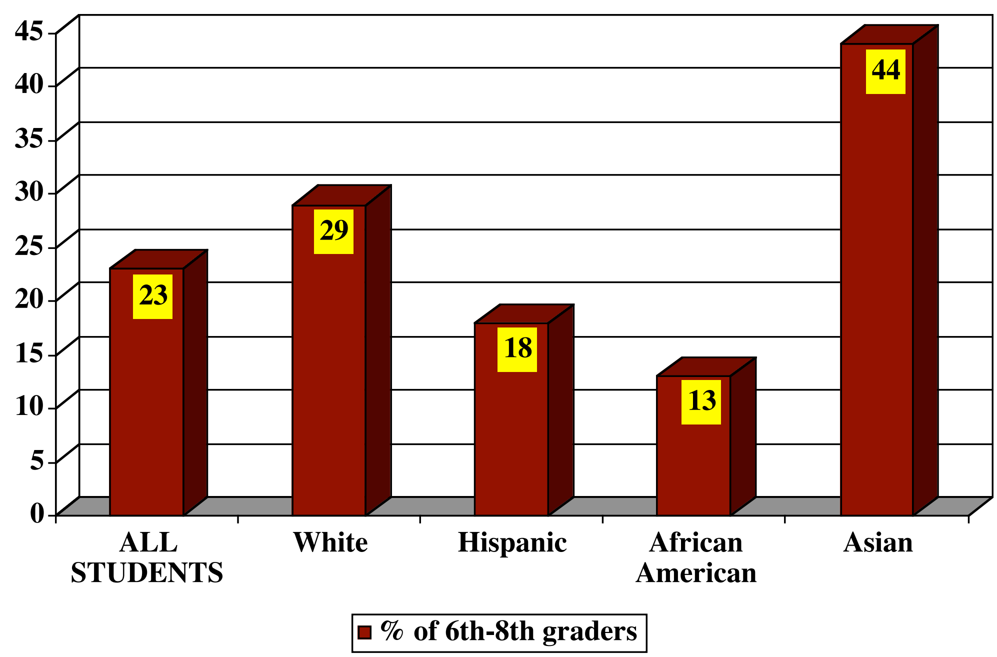
The state of Massachusetts took this access and equity challenge seriously by extending grade level access and population access. Massachusetts founded the National Center for Improving Student Learning and Achievement in Mathematics and Science with the intention of "Algebrafying" the K-12 curriculum (Kaput, 2000). Also in Massachusetts, noted teacher and Civil rights activist Robert Moses aimed his "Algebra Project" directly at previously neglected minority youngsters (Checkley & Moses, 2001). His goal was to form a united community of citizens equipped with cutting-edge technology that would reach out to others with the sole purpose: "Each One Teach One."

Similar to the situation in Massachusetts, the valley area in south Texas, which has a highly concentrated Hispanic minority population, has traditionally suffered with respect to instruction and curriculum. One research study conducted in south Texas collected both qualitative and quantitative data to determine the type of instruction available for Algebra I and II students and the level of achievement for Algebra I students. Results showed that instruction was directly influenced by requirements of a statewide test (Texas Assessment of Academic Skills, TAAS). When students were given a standardized test that measured algebraic skills and concepts, their achievement exactly mirrored the instructional method and curriculum. Since instruction focused on skills and procedures and followed the lecture and supervised-practice teaching methods, students performed well on problems requiring particular skills and processes and performed poorly on open-ended and higher order thinking problems (Telese, 2000).

One way the state of Texas has tried to monitor student success rates in mathematics is through the TAAS test implemented in 1990 and administered to all students statewide along with end-of-course exams in specific disciplines. The *Educator's Guide to Texas Essential Knowledge and Skills (TEKS)-based Assessment* is a handbook designed to show teachers which of the components for each course, such as Algebra I, will be ultimately tested by TAAS (Texas Education Agency (TEA), 2000). Each year, the TEA publishes a report called the Texas Student Assessment Program that gives detailed information on student performance results. Statewide and regional results on the TAAS and end-of-course examinations along with various other studies are outlined and compared to previous years. The validity and reliability of this test is rigorously monitored by the TEA (Cruse & Twing, 2000; Smisko, et al., 2000).

However, on the access and equity scale, Texas has been slower in general to respond to students' needs. Figure 2 shows the percent of Texas students taking algebra in grades six through eight.

Figure 2
Percent of Texas Students Taking Algebra I in Grades Six through Eight For All Students and by Ethnicity

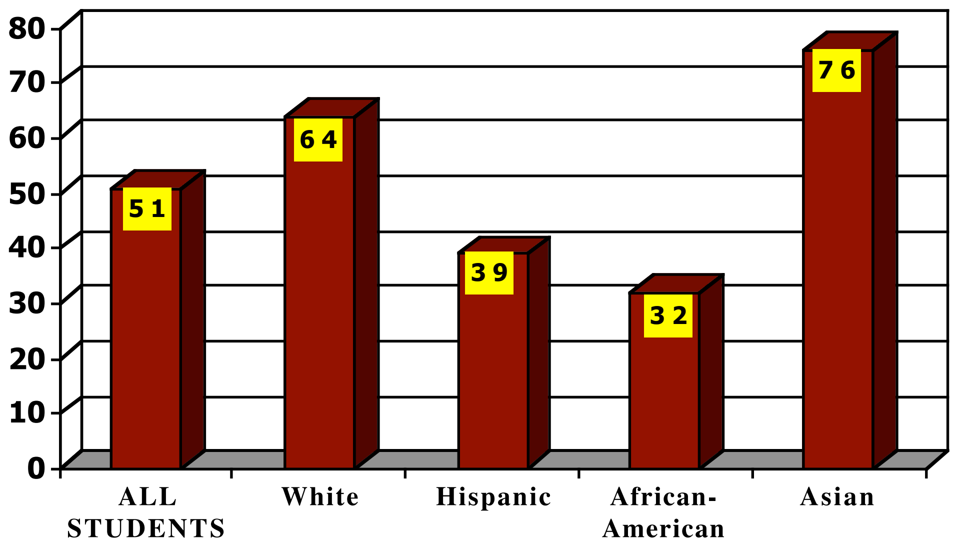


Note: Data taken from TEA, 2001.

Figure 2 demonstrates that about one in four (23%) of all Texas' students take algebra in grades six through eight. Four out of 10 (44%) of the Asian students take algebra at this grade level compared to three out of 10 (29%) of the White students. Only two out of ten (16%) of the Hispanic students take algebra at this grade level compared to one out of ten (13%) of the African-American students.

Figure 3 charts all grade levels of success in Algebra I. It shows that only 51% of all Texas students pass Algebra I. Seventy-six per cent of Texas' Asian students and 64% of Texas' White students pass Algebra I, while only 39% of Texas' Hispanic students and 32% of Texas' African-American students are successful.

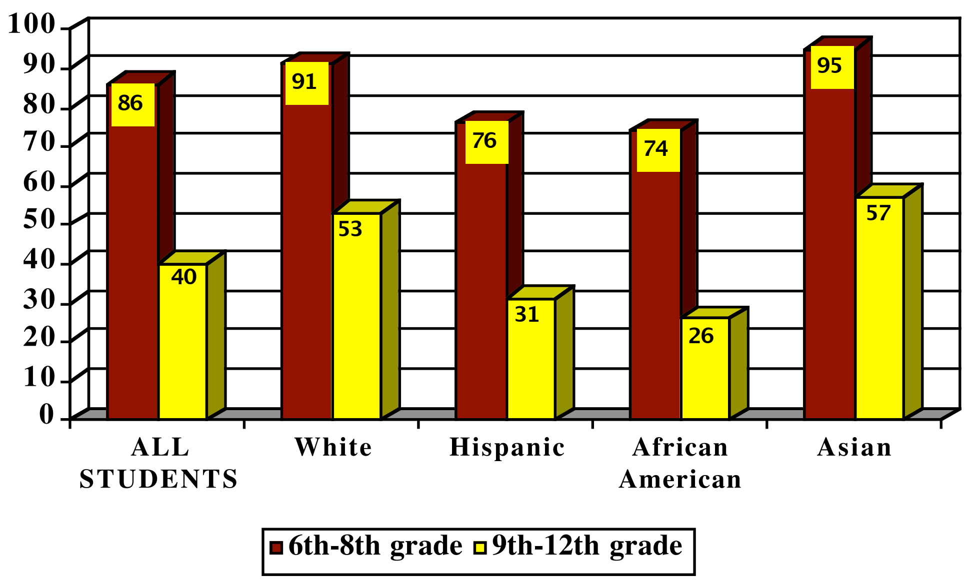
Figure 3
Percent of Texas Students Passing Algebra I For All Students and by Ethnicity



Note: Data taken from TEA, 2001.

Another interesting facet of students who are exposed to algebra in Texas can be seen in Figure 4, which describes the percent of Texas students who pass algebra by grade level and by ethnicity.

Figure 4
Percent of Texas Students Passing Algebra I by Grade Level for All Students and by Ethnicity



Note: Data taken from TEA, 2001.

Two grade levels are charted, sixth through eighth in the shaded bars and ninth through twelfth in the nonshaded bars. Note that the order of the participants is the same for each of the grade groups (most passing, Asian students; second, White students; then Hispanic students; and last, African-American students). The most dramatic revelation of the TEA data is that students of all ethnic backgrounds are far more likely to pass algebra in grades six through eight rather than in grades nine through twelve.

A Look at the Mathworks Perspective

In Texas, one small group of thoughtful, committed citizens has been addressing these problems in mathematics for 12 years. Initially funded by grants from Southwest Texas State University (SWT), Mathworks—then called the Math Institute for Talented Youth—began in 1990 in conjunction with the SWT Honors Summer Math Camp for high school students and has now grown to include students from elementary through high school levels. The name of the program, Mathworks, was chosen to emphasize that "math works" for all students and that the task of educators is to develop students' talents. From its inception, the program has insisted that children, parents, and teachers raise their expectations for what children can do in mathematics.

The goal of the Mathworks program is to provide a firm mathematics foundation for students of all backgrounds and socioeconomic levels. To reach this goal, Mathworks has built a center that integrates the development of mathematics curricula, student and teacher training (pre-service and in-service) programs, and outreach programs into a cohesive plan of action. The center's primary objectives are to develop model programs for training students and teachers in summer math camps, to develop model programs for preparing young students for algebra, and to train vertical teams of teachers who are committed to promoting systemic change. Mathworks assesses the effectiveness of each of these programs, redesigns them as necessary, and implements them in undergraduate and graduate teacher preparation programs as well as summer camps.

In Summer 2001, Mathworks had programs in many Texas cities—Alamo, Austin, Blanco, Donna, Edcouch, Edinburg, Elsa, Harlingen, Hidalgo, Houston, La Joya, La Villa, Lockhart, Lyford, Monte Alto, Pharr, Port Isabel, Port Lavaca, Progresso, Rio Grande City, Roma, San Benito, San Juan, San Perlita, and Zapata—and trained more than 1,400 students. Altogether, Mathworks hosted 29 camps throughout Texas and trained a total of 140 teachers at six teacher-training centers in Laredo, Mission, McAllen, Mercedes, Brownsville, and San Marcos. Much of Mathworks' efforts are focused on the Rio Grande Valley in south Texas where many students do not have the opportunities afforded students in other parts of the state. For example, Progreso ISD in rural south Texas has a student makeup that is 99% Hispanic, 73% limited English proficiency, and 95% economically disadvantaged. As might be anticipated, Progreso ISD has a difficult time recruiting and retaining qualified teachers.

Mathworks programs are designed to develop the creative mathematical talents of each student through the use of discovery learning and innovative curricula. Students and teachers learn math connections and concepts deeply, thereby increasing confidence and interest in math related subjects. Mathworks helps teachers realize that a problem-centered classroom fosters independent thinking, whereas an answer-centered classroom produces mechanical responses.

The Mathworks Junior Summer Math Camp (JSMC) is a 2-week (10 day, 4 hours a day) summer program for students in grades 3-9. Teachers attend a concurrent 2-week intensive program involving hands-on activities with the students in the morning under the direction of a master teacher and teacher training classes taught by university professors in the afternoon. Table 1 provides an overview of the demographics of the students who attended the Mathworks JSMC from 1996 to 2002.

Table 1
Demographic Data of Students in Mathworks Junior Summer Math Camp

	Male	Female	White	African-American	Hispanic	Asian	Other
1996	18	21	25	2	12	0	0
1997	30	30	35	3	19	3	0
1998	48	38	44	6	33	3	0
1999	110	74	79	21	78	6	0
2000	341	417	68	19	644	19	8
2001	630	770	126	34	1190	35	14
2002	723	748	150	103	1024	35	31

The Orleans-Hanna Algebra Prognosis Test was given as a pretest and posttest to students in the JSMC. Table 2 summarizes the national means on this test and compares those means to the JSMC students' pre- and posttest mean scores. A paired *t* test applied to the students' pre- and posttest scores showed significant and substantial gains in students' mathematics competence over the 2-week program.

Table 2
National Scores on the Orleans-Hanna Algebra Prognosis Test and JSMC pretest/posttest scores for years 2001 and 2002

	Number of students	Pretest Mean	Posttest Mean	Difference	*p* value
7th grade national average	9195	29.10			
8th grade national average	6743	31.30			
2001 JSMC (Level 1)	1125	19.05	23.31	4.26	.0000
2001 JSMC (Level 2)	193	28.51	31.36	2.85	.0000
2001 JSMC (Level 3)	49	30.35	31.71	1.36	.0573
2002 JSMC (Level 1)	664	10.75	14.50	3.75	0.000
2002 JSMC (Level 2)	264	15.99	18.88	2.89	0.000
2002 JSMC (Level 3)	236	27.84	31.37	3.86	0.000

Mathworks also organizes an Honors Summer Math Camp (HSMC), a 6-week residential program for high school students and teachers. Table 3 reports the demographic data of the students who attended the HSMC from 1991 to 2002.

Table 3
Demographic Data for Students Who Attended HSMC from 1991 to 2002

	Male	Female	White	African-American	Hispanic	Asian	Other
1991	8	8	7	5	3	0	1
1992	10	8	10	6	2	0	0
1993	19	20	16	3	11	5	4
1994	19	21	11	5	17	11	3
1995	27	26	17	7	16	13	0
1996	23	24	14	3	17	12	1
1997	24	25	20	6	13	9	1
1998	27	21	25	5	9	9	0
1999	22	26	22	5	7	14	0
2000	25	27	22	3	9	18	0
2001	26	27	17	7	14	15	0
2002	30	28	13	9	22	14	0

Table 4 shows the number of teachers attending both the JSMC and the HSMC from 1998 to 2002.

Table 4
Number of Teachers Attending the JSMC and the HSMC from 1998 to 2002

	JSMC	HSMC
1998	12	6
1999	30	8
2000	77	9
2001	137	8
2002	116*	5*

*Delays in funding decisions by local school districts prevented many teachers from attending the JSMC and HSMC in 2002.

Mathworks gives all students the confidence and skills they need to succeed in higher level challenges as evidenced by their proven ability in regional, national, and international arenas. In fact, Mathworks students have enrolled and graduated from institutions such as the Massachusetts Institute of Technology, the California Institute of Technology, Rice, Harvard, Yale, Stanford, the University of Texas, and Texas A&M with over 60% majoring in math, science, and engineering. In 2001, a team of Mathworks students finished in fourth place in the US at the prestigious Siemens Westinghouse Science and Technology Competition. In 2002, at this same national competition, with only scant regional data available, a Mathworks student led the number one regional team in Texas. Mathworks sent a team of four students to the international Po Leung Kuk Primary Mathematics World Contest in 2001 and 2002. The 2001 team, the first US team to compete in this international contest, won two runner-up trophies. One student got first honors for a perfect individual test, and two students received third honors awards. The team finished thirteenth out of 40 teams from around the world. The 2002 team received one first honors award, one second honors award, and one third honors award. This team placed seventh in the world and first among the non-Asian teams. Once again, there were 40 teams from around the world. In 2001, Governor Rick Perry awarded Dr. Warshauer, Director of the Mathworks Program, the first Texas Star Award for Closing the Gaps in education. Also in 2001, Dr. Warshauer won the national Presidential Award for Excellence in Science, Mathematics, and Engineering Mentoring given by President George Bush.

Mathworks reflects the following basic tenets, among others, of current research in mathematics education:

1. Students need to make use of technology, pursue deeper aspects of each subject, and be allowed to be more creative (McMullin, 2001).
2. Experiment results show the need for Algebra courses involving modeling and problem solving (Fox & West, 2001).
3. The discovery method of teaching improves student achievement (Yarborough, 1999).
4. When teachers apply innovative Algebra teaching techniques to reduce students' anxiety levels, both students and teacher become more engaged in the topics (Bankhead, 1997).
5. Teacher content knowledge increases when teachers use reform teaching methods (Sharon, 2002).
6. Students need to construct and reflect when solving Algebra problems (Swan, 2000).
7. Students who take Algebra early have a substantially higher rate of taking advanced mathematics courses than students who do not (Ma, 2000).
8. Students learn more when their attitudes towards the subject are positive (Powers & Hartley, 1999).

Conclusion

Mathworks, an internationally recognized mathematics institute housed at Southwest Texas State University, has the express goal of teaching higher-level mathematics to all students and focuses on underserved and economically disadvantaged students who may not have previously had this learning opportunity. Mathworks has developed unique student and teacher (pre-service and in-service) training programs that have been shown to yield outstanding results through repeated assessments over the past 10 years. One of the essential aspects of Mathworks is to foster encouraging and dynamic mathematics learning environments enabling all students to succeed and excel in math. Mathworks provides a setting in which programs and ideas come together by integrating curricula, student training, and teacher training with the needs and requirements of our technology-driven economy. Mathworks continues to build a community of students, teachers, parents, administrators, and partners from industry and federal, state, and local governments, who are dedicated to solving the problems of and promoting systemic change in mathematics education in today's world.

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