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POLICY BRIEF

How to Strengthen K-12 Mathematics Education in Massachusetts:

Implications of the National Mathematics Advisory Panel's Report

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Introduction

This position paper suggests how Massachusetts can strengthen K-12 mathematics education in its schools, drawing chiefly on the findings and recommendations presented in the final report of the National Mathematics Advisory Panel (henceforth referred to as the Panel). The Panel's report was released in March 2008 after two years of work and deliberation by seventeen researchers and scholars appointed by Secretary of Education Margaret Spellings. Its findings and recommendations are based on a thorough review of the evidence from all the best available high quality research. Although

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the Panel sought to address all the elements in the Presidential Executive Order (No.13398, April 18, 2006) authorizing its establishment, it concentrated on the Order's main thrust--how to improve mathematics education in the elementary and middle school, based on the best available scientific evidence, so that more students would be successful in Algebra I, the gateway to advanced study in mathematics.

Section I provides a brief history of mathematics education in this country to help readers understand why the Panel was appointed and charged with this task. Section II provides a brief description of school algebra to give readers a better understanding of this branch of mathematics.

Section III presents the major findings and recommendations in the Panel's report on K-12 mathematics curricula, instruction, and large-scale assessment, together with their relevance for state or local education policy-making in Massachusetts. The release of the Panel's report in March fortunately coincides with a review of the state's curriculum framework in mathematics by a committee of educators appointed by the state's Department of Elementary and Secondary Education (DESE) for the purpose of making recommendations to the Board of Elementary and Secondary Education (BESE) on ways to strengthen current K-12 standards in mathematics. Section III concludes with suggestions to our state legislature on fundable programmatic initiatives that would expand opportunities for increasing mathematics achievement by Massachusetts high school students.

Section IV presents the major findings and recommendations in the Panel's report on many components of teacher education, together with their relevance for policy-making in the Bay State. At this time, the DESE is also reviewing state regulations on educator preparation, licensure, and professional development in order to make recommendations to the BESE for changes that will strengthen the academic preparation of prospective and current teachers in the state and increase the number of mathematically knowledgeable and effective teachers in our schools.

Section IV also presents a number of suggestions for reforming teacher education in the Bay State, drawing on my own research on licensure requirements and teacher testing policies. These suggestions reflect two major findings in the Panel's report: the positive relationship between teachers' knowledge of mathematics and their students' achievement in mathematics, and the lack of research evidence for other characteristics of an effective teacher of mathematics. These two findings do not mean that pedagogical skills are unimportant or that students need only mathematically knowledgeable teachers in order to learn mathematics. The findings simply underscore that mathematically competent teachers are needed in every mathematics classroom.

I. A Brief History of Mathematics Education in the United States

It may be helpful at the outset to explain briefly how this country arrived at a point in its educational history at which such a panel was necessary. The United States first became aware of the need to improve mathematics education nationally during World War II, a time when the small number of high school graduates with adequate knowledge of mathematics became woefully evident. In 1950, Congress created the National Science Foundation (NSF). The launch of Sputnik in 1957 added a sense of urgency to efforts to improve mathematics education. The National Defense Education Act in 1958 provided funds for qualified students to pursue advanced education in the sciences and engineering. In fact, more students majored in mathematics in the 1960s and early 1970s than at any other time in the nation's history.

At the same time, NSF funded the work of mathematicians and teachers at a variety of universities to develop what became known as the "New Math." By 1962, a definitive version of SMSG (School Mathematics Study Group) Mathematics was being used by over 400,000 secondary students throughout the country. Although the New Math was criticized-and soon abandoned-for a perceived stress on mathematically able students, its formalism, and the difficulty that parents had in understanding it, it led to important changes in the high school mathematics curriculum-the integration of trigonometry into algebra II, the introduction of calculus, and the integration of analytic geometry into calculus.

During this period, publishers of school textbooks came to serve as another force shaping the content and structure of mathematics education. Between 1965 and the 1980s, the algebra textbooks authored (or co-authored) by Mary Dolciani alone accounted for approximately two-thirds of all the algebra texts used in the United States. Her publisher, Houghton Mifflin, and other publishers of school algebra textbooks integrated many of the SMSG ideas into their textbooks, thus keeping much of SMSG's mathematical content in the high school curriculum.

However, in the late 1960s, as part of the War on Poverty, the federal government drastically shifted gears and turned its attention in education almost completely to the problems of low-performing students. Working with the United States Office of Education, the NSF directed its research to include a variety of activities to benefit "educationally disadvantaged students." In 1972, the federal government created the National Institute of Education within the United States Office of Education to support research on ways to improve student performance, especially in reading and mathematics. The 1970s and early 1980s also saw an emphasis in the curriculum on "basic skills" and large-scale assessment of student achievement in these two areas. In 1983, "A Nation at Risk" startled the nation with its bleak portrayal of the condition of public education. But attention remained focused on low-performing minority children because the gap between their level of achievement and that of other students was unacceptable.

That was the context in which the National Council of Teachers of Mathematics (NCTM), the chief professional organization in mathematics education, issued *Curriculum and Evaluation Standards for School Mathematics* in 1989, a first attempt by a professional education organization to provide national standards in a subject area. NCTM presented standards for three broad spans of grades, K-4, 5-8, and 9-12, addressing what it called algebra at Grades 5-8 and 9-12.

The 1989 document was applauded for urging K-12 textbook publishers to present mathematics in ways that might better engage student interest and to suggest a variety of teaching strategies. However, the implementation of these standards soon led to concerns about a stress on pedagogy over mathematical substance. A major criticism was that these curriculum and evaluation standards were teaching, not learning, standards. Prominent mathematicians began to voice objections to the stress on calculator use in the early grades,[1] the over-emphasis on student-developed algorithms at the expense of standard algorithms, and the de-emphasis at the high school level on computation in algebra and proof in Euclidean geometry. In general, they found the high school standards lacking in mathematical integrity. They also noted the absence of mathematicians in the development of the 1989 document.[2]

In 2000, NCTM issued its *Principles and Standards for School Mathematics* (PSSM) for narrower spans of grades, PreK-2, 3-5, 6-8, and 9-12, now addressing what it called algebra at all grade levels. Although NCTM had included some mathematicians in the development of this document and claimed that it sought to address the criticisms of the earlier document, PSSM also generated criticisms from mathematicians and others. Moreover, a petition with the names of over 200 scientists, mathematicians, and other public figures was sent to then Secretary of Education Richard Riley in 1999 urging him to publicly withdraw the United States Department of Education's endorsement of ten K-12 mathematics programs based on NCTM standards and reform math tenets as "exemplary" or "promising" and to include well-respected mathematicians in any future evaluation of mathematics curricula conducted by the United States Department of Education.

Despite mounting criticisms by mathematicians, scientists, and mathematically literate parents, whose comments were and are easily accessible on NYC HOLD and Mathematically Correct, the major web sites coordinating "grassroots" communications on issues in mathematics education, the media regularly portrayed these criticisms incorrectly. The debates were (and continue to be) characterized as a disagreement between forward-thinking mathematics educators who wanted a "conceptual approach in which students discover algorithms on their own, investigate mathematical relationships, and explore multiple ways to solve problems," and "traditional" mathematicians and parents who wanted only rote memorization and computational fluency.

As a matter of fact, almost all of those who expressed criticism of the new curricular materials strongly support an approach to mathematics that develops conceptual understanding. At the heart of the disagreement was whether students were acquiring a foundation in arithmetic and other aspects of mathematics in the early grades that prepared them for authentic algebra coursework in Grade 7, 8, or 9. If they were not acquiring this foundation for algebra and therefore not learning authentic algebra by Grade 9 at the latest, they could not successfully complete the advanced mathematics courses in high school that would prepare them adequately for freshman college courses using mathematics or in mathematics, or for their freshman year in four-year engineering colleges. It was in this context that the Panel was formed, and it is in this context that the recommendations in its final report should be understood.

II. School Algebra: A Brief Description[3]

Although algebra has roots in ancient Babylonia and Greece, the word "algebra" and some of its early applications came to Europe through the famous 9th century book by al-Khwarizmi of Baghdad, the title of which contained the Arabic word "al-jabr." His book had to do with the decomposition and reassembly of expressions or symbols representing numbers not necessarily (or as yet) specified. As school algebra is today, the earliest algebra was designed to solve equations that involve an unknown number, using the structural properties of our number system to split and recombine terms in ways conducive to the result. Algebra is the elucidation and application of those structural properties.

To state these properties succinctly and easily requires the use of symbols because they are statements of truths that apply to more than the particular numbers one might be interested in at any given moment. Developed in Europe after the Renaissance, symbols for unspecified numbers (e.g., x, y) and operations and relations (e.g., +, =) have made possible a precise, visible expression of these structural properties. They are of such importance that a firm grounding in the manipulation of symbolic expressions and in the solution of equations and inequalities is necessary before students can comprehend anything in advanced mathematics and science.

Necessary as they are for keeping complicated ideas present to the mind, the symbols are just a peripheral feature of algebra-its alphabet, as it were. Al-Khwarizmi did not use them. Even the Italian algebraists of the sixteenth century, who solved the cubic and quartic equations, used clumsy words and phrases, not brief symbols. It is thus only partly correct to call algebra "symbolic arithmetic." It may be called generalized arithmetic, but that popular phrase does not explain the logical connection between algebra and arithmetic.

School arithmetic, for example, will produce the fraction 144/5, or its equivalent 28 and 4/5, when a fractional equivalent for the quotient (16)/(5/9) is asked for, and it can apply this calculation to the imagined problem of finding how many stacks of paper of thickness 5/9 inches can be made from one stack 16 inches high. This is not algebra, but implicit in the solving of this arithmetic problem is the use of the algebraic theorem "if a, b, and c are non-zero real numbers, then $a/(b/c) = ac/b$", a theorem which can be proved only on the basis of the definitions and axioms that initially describe the real number system.

All students can and should learn what the necessary structural statements are for the common number systems that we use daily, how to express them using the standardized symbolism of modern algebra, how to use them to describe common physical situations including financial and geometric ones, and then how to make use of these structures and their symbolism to find numerical (or symbolic) answers to questions that occur in these contexts. A firm grasp on this much algebra is irreplaceable preparation for trigonometry, analytic geometry, and calculus, as well as for more advanced mathematics.

III. The K-12 Mathematics Curriculum: Standards, Instruction, and Assessment

First, a brief chronology of mathematics reform in Massachusetts since the passage of the Education Reform Act in 1993 should be given. In 1994, the Department of Education (as it was then called), in conjunction with committees of educators and others, began to develop K-12 curriculum frameworks for all subjects. In December 1995, the Board of Education (as it was then called, hereafter referred to as the "Board") approved the state's first mathematics and science curriculum frameworks. Based on NCTM's *Curriculum and Evaluation Standards for School Mathematics,* the standards in the mathematics curriculum framework served as the basis for the state's first mathematics assessments, given from 1998 to 2001.

In March 1999, then Governor A. Paul Cellucci appointed James Peyser, then Executive Director of the Pioneer Institute, as Chairman of the Board. At the time, the Department had already begun to work with two committees of educators and others to revise and strengthen the 1995 mathematics and science curriculum frameworks. The Board and newly appointed Commissioner of Education, David Driscoll, asked Department of Education staff to revise its educator licensure regulations at the same time in order to incorporate, among other things, the K-12 standards that had been developed in all subject areas. In the fall of 2000, after a series of disputes, the Peyser Board approved a thoroughly revised version of the 1995 mathematics curriculum framework, which now served as the basis for state mathematics assessments. It also approved a major revision of the state's licensure regulations, which, in turn, served as the basis for a revision of the state's teacher licensure tests, another mandate of the Education Reform Act first given in 1998.

In 2005 and 2007, the state's scores on the grade 4 and grade 8 mathematics tests given by the National Assessment of Educational Progress (NAEP) placed the Bay State first in the country. As the scores of regular students significantly increased, so did the scores of low-income students in the state. But despite dramatic gains in mathematics in the past seven years, the continuing gap between low-income and other students highlights the importance of the Panel's findings and recommendations. Massachusetts is at the bottom of the state list on gap-closing. But, when the mathematics scores of its low-income students are compared with the *scores of low-income students in the other states,* it turns out that these students are tied for first place in Grades 4 and 8. Their gains show up on state, or Massachusetts Comprehensive Assessment System (MCAS), tests as well. For example, in 2001, the year that the high school graduation requirement became effective, only about 15% of black and Latino tenth graders scored at the proficient and advanced levels on the MCAS mathematics test. The percentages rose to about 45% in 2007, a three-fold increase in the percent of those who are proficient or advanced. Interestingly, the 2007 percentage of black/Latino 10^{th} graders who are proficient or advanced (45%) is only slightly below the percentage of white students who were proficient or advanced in 2001 (50%).

Looked at this way, the figures tell students and teachers a very different story from the usual analysis. As the others have risen, so have the state's low-income students. The gap is large not because the performance of the state's low-income students is worse than those in other states or because they haven't shown much improvement but because the performance of the state's other students is so much better than those in other states. All students need to continue to increase their achievement in mathematics, but implementation of the Panel's recommendations may especially benefit low-income students, who need to learn mathematics at a faster pace than the other students do.

The Panel's 45 major findings and recommendations and their implications for Massachusetts are discussed below. First, here are several general points that the Panel made in its report that I wish to highlight.

- School algebra should be consistently understood in terms of the 27 major topics of school algebra that the Panel lists under six categories in Table 1 of the report. These six categories are: symbols and expressions; linear equations, quadratic equations; functions; the algebra of polynomials; and combinatorics and finite probability. These 27 topics have traditionally been taught in Algebra I and Algebra II courses.

- Success in Algebra I rests on proficiency with whole numbers, fractions, and certain aspects of geometry and measurement. These are the critical foundations for the study of algebra. As the Panel noted, knowledge of fractions is the most important foundational skill that is not developed effectively in our students.

- The benchmarks proposed by the Panel for acquiring these three sets of foundational skills are based on comparisons of national and international curricula and should guide classroom curricula, mathematics instruction, textbook development, and state assessments.

- A higher percentage of students should be adequately prepared for and offered an authentic Algebra I course or its equivalent at Grade 8.

- Conceptual understanding, computational and procedural fluency, and problem solving skills are equally important and mutually reinforce each other. In the Panel's judgment, debates regarding the relative importance of each of these components of mathematics are misguided.

III.A. How to Strengthen the Massachusetts K-12 Mathematics Standards

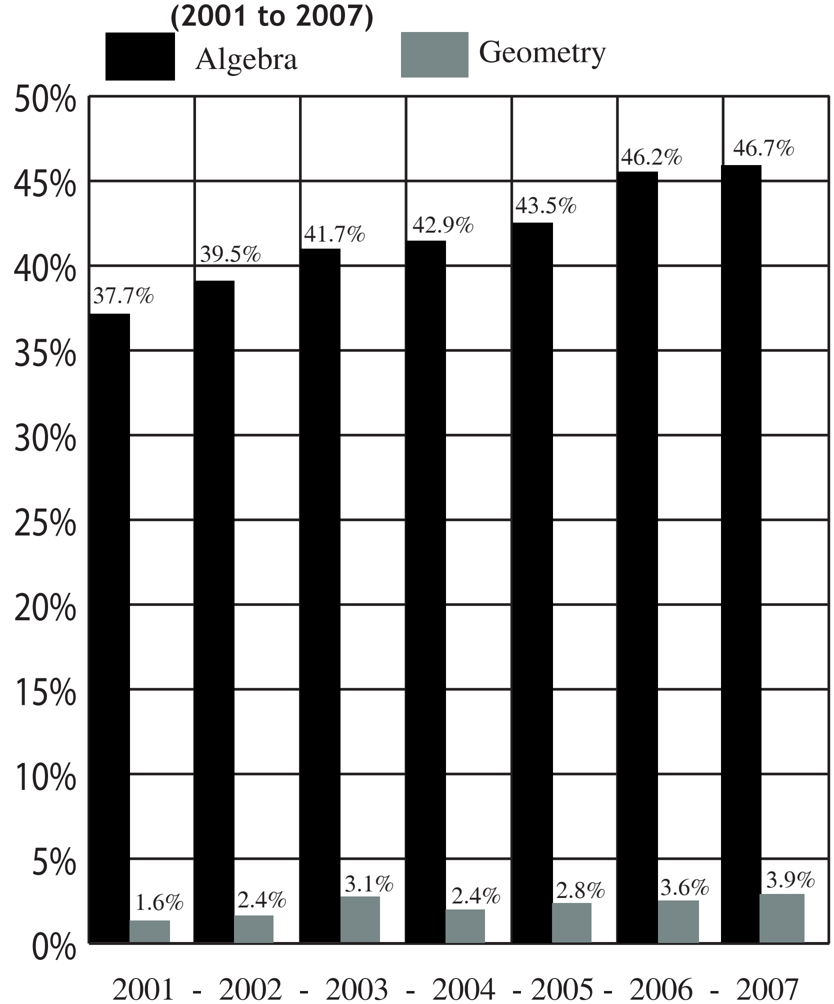
1. As indicated in the Panel's report, K-7 standards should emphasize proficiency with the key topics or concepts that facilitate fluency with *whole numbers, fractions, and particular aspects of geometry and measurement*. The Panel concluded that a repetition of topics year after year without the expectation of closure should be avoided. This recommendation should be reflected in the revision of the state's K-12 mathematics standards.

2. As indicated in the Panel's report, standards in the *primary grades* (K-3) should concentrate on basic arithmetic concepts and procedures as do the curricula in the highest-achieving countries on the Trends in International Mathematics and Science Study (TIMMS). This recommendation should be reflected in the revision of the state's K-12 mathematics standards.

3. As indicated in the Panel's report, the standards must show *logical progressions* from less difficult or complex topics to more difficult or complex topics, within a grade and from grade to grade. This recommendation should be reflected in the revision of the state's K-12 mathematics standards.

4. As suggested in the Panel's report, the standards from K to Grade 6 or 7 should be sufficiently *rigorous and focused* to enable students who have achieved them to enroll in an authentic *Algebra I* course by Grade 8. This recommendation should be reflected in the revision of the state's K-12 mathematics standards.

Table 1: Percent of Grade 8 Students in Massachusetts Taking Algebra or Geometry (2001 to 2007)



Source: Massachusetts Department of Education: MCAS Survey Data.

In Massachusetts, the (albeit slowly) increasing percentage from 2001 to 2007 of Grade 8 students who report on MCAS surveys that they are enrolled in an Algebra I course or in Geometry (suggesting that they have probably taken Algebra I in Grade 7) is a positive trend, and *may be a major factor accounting for the state's lead* on the mathematics tests given by NAEP in Grades 4 and 8 (see Table 1). For the sake of equity, schools should be encouraged to increase this percentage so long as they also ensure the availability of an authentic Algebra 1 course in Grade 7, 8, or 9 for these students.

5. The Panel's report notes that current *integrated approaches* at the high school level may make it more difficult for students to take advanced mathematics course work in their senior year than a single-subject approach, beginning with Algebra I in Grade 8, that enables students to take an Algebra II course in their sophomore year.

This possibility, which was based on an analysis of one state's standards, is supported by a report to the Massachusetts Board of Education in 2000 on the sequence of mathematics courses needed for taking calculus in grade 12. This report was based on responses from mathematics department chairs in 17 school districts in Massachusetts; almost all said that in order to take calculus in grade 12, most students would need to take what they called an honors level Algebra I course in Grade 8.[4]

III.B. How to Strengthen Mathematics Instruction in Massachusetts

It is important to note that the Panel did not find definitive evidence from high quality studies to support many of the instructional practices currently promoted in mathematics education. Thus the Panel chose to offer a broad recommendation to teachers and teacher training institutions that, in effect, fosters an eclectic approach to instruction. As its report states, instructional practices should be informed by high-quality research when available, and by the best professional judgment of experienced and accomplished classroom teachers. The report stresses that evidence from high quality *research does not support either a wholly student-centered approach or a wholly teacher-directed approach* to mathematics learning.

1. As the Panel's report clearly states, students should be expected to develop automatic and accurate execution of the standard algorithms and use these competencies to solve problems. This recommendation should be clearly reflected in the revision of the state's K-12 mathematics standards.

2. The Panel recommends that students with learning disabilities and other learning problems receive on a regular basis some explicit *systematic instruction* (carefully defined in the Panel's report) in order to learn mathematics.

3. The Panel also recommends regular use of *formative assessment* (ongoing monitoring of student learning to inform instruction) for students in the elementary grades, especially if their teachers have additional guidance on using the assessment to design and to individualize instruction.

4. Further, the Panel found that *mathematically advanced students* can learn mathematics much faster than students proceeding through the curriculum at a normal pace, with no harm to their learning, and thus recommends that they should be allowed to do so.

5. However, as the Panel's report states, while *small group work and the use of problems contextualized in daily life* may produce gains in mathematics achievement, the evidence indicates that they do so only under very specific conditions, at certain grade levels, and in certain areas, chiefly in computation skills. A clear implication is that instructional practices should not prioritize or emphasize small group work or problems contextualized in daily life (often labeled real-world problems).

6. Moreover, as the Panel's report states, caution should be exercised in the use of *calculators*. To the degree that they impede the development of automaticity, fluency in computation will be adversely affected. High quality research shows that calculator use has limited or no impact on conceptual development, calculation skills, and problem solving. Moreover, this research is very dated and did not examine the effects of long-term calculator use. The Panel's cautions should be clearly reflected in the revision of the state's K-12 mathematics standards.

7. As implied by the Panel's report, teachers and administrators should look for and choose mathematics *textbooks* for students that are more *compact and coherent* than the many excessively long textbooks that now dominate the market.

8. Although most teacher educators and professional development providers highly recommend a technique called *Differentiated Instruction* (DI) at all educational levels, there is no basis in research for promoting DI in the mathematics (or any other) classroom. The Panel could not evaluate the quality or weight of the evidence for DI because there is no empirical research on it at all.

III.C. How to Strengthen the State's K-12 Assessments

The Panel's review of the research literature and other relevant studies resulted in two important recommendations for large-scale assessments. One involves the use of constructed-response test items, the other the use of "patterns" as test items and as part of an algebra strand. A Panel finding suggests a third.

1. The Panel found that a *constructed-response format*, especially the short answer response, does not measure different aspects of mathematical competency (or more authentic mathematical skills), as is often claimed. This implies that state assessments in mathematics could consist chiefly if not completely of multiple-choice questions. This would lead to an enormous savings in cost, speed in the delivery of results, and greater if not complete objectivity in scores.

2. The Panel noted that the prominence given *patterns* in PreK-8 is not supported either by comparative analyses of curricula or by mathematical considerations. It recommends that "algebra" problems involving patterns be greatly reduced on NAEP and state tests. This recommendation should be followed in constructing state and other K-12 assessments.

3. The Panel noted that immediate recall of number facts frees the "working memory" for solving more complex problems. This means that automatic recall of number facts (such as the times tables) is needed to execute the standard algorithms automatically. This finding should be reflected on state assessments in some way, possibly by requiring teachers to certify whether each student has instant recall of all number facts.

The Panel's recommendation that our schools should prepare an increasing number of students to take an *authentic Algebra I course in Grade 8*, if not earlier, and offer such a course in Grade 8, if not earlier, has significant implications for the state's assessments at the secondary level. To encourage implementation of this recommendation, the state could offer as part of MCAS an end-of-course test for Algebra I open to prepared students at any secondary grade level (Grades 7-12). Such an offering would make an alternative assessment available to prepared students at the secondary grades and be consistent with a growing trend in other states to use end-of-course tests for Algebra I, geometry, and Algebra II.

III.D. How to Increase Opportunities for Student Support and Challenge

1. The legislature should fund several *regional mathematics and science high schools* throughout the state, open to students who pass qualifying examinations. These high schools can be staffed at the principal's discretion by teachers who have passed the state's licensure tests and the Criminal Offender Record Information (CORI) check but who do not have to be enrolled in or have completed an "approved program." As the Panel notes, teachers' knowledge of mathematics is related to student achievement; research reveals no other characteristics of effective mathematics teachers.

2. The legislature should fund expansion of our *technical career high schools*, with updated mathematics and science programs, where necessary, for various technical trades or occupations. These schools should be allowed to use qualifying tests for entry to special programs.

3. The legislature should fund, pilot, and evaluate a *transition year* for students completing Grade 6 who are two or more years below grade level in reading, mathematics, and science and who did not pass the MCAS tests given in Grade 6. This should be a reading-intensive program that enables these students to master whole numbers and fractions before continuing on to middle school and regular courses there.

4. The legislature should fund, pilot, and evaluate a *mathematics class* focusing on the Critical Foundations for Algebra *for low-performing students* in Grade 9 or 10 to enable these students to pass the Grade 10 MCAS.

IV. Preparation, Licensure, and Professional Development for Teachers of Mathematics

The Panel's report highlights several important findings on teacher education based on its review of the available high quality research in this area. Perhaps its most important finding is that *teachers' knowledge of mathematics is related to student achievement in mathematics*. It found no evidence for any other characteristic of an effective teacher of mathematics. This does not necessarily mean that mathematical knowledge is the only characteristic of an effective teacher of mathematics; it means only that there is no basis in research to require other qualities. In addition, the various reviews of the high quality research available found no evidence to support any component of teacher training and professional development as currently conceived and practiced across the country in our institutions of higher education.

- The report found no difference between *traditional and alternative routes* or pathways to licensure with respect to their relationship to student achievement.
- It found no relationship between *certification* (i.e., licensure) and students' mathematics achievement.
- It noted that state *licensure tests* for those who teach mathematics, as generalists or as specialists, vary in the amount and level of the mathematics assessed, and in some cases assess no mathematics content at all.
- It found a relationship between the *undergraduate mathematics coursework* taken by high school mathematics teachers and students' mathematics achievement. However, it found no relationship between the undergraduate mathematics coursework taken by elementary and middle school teachers and students' mathematics achievement, suggesting that these teachers may not have taken appropriate mathematics coursework in their undergraduate programs.
- It found few significant effects of *professional development* in mathematics on students' mathematics achievement. And in those few studies with significant effects, it found no hint about what specific factors accounted for the results.
- It found no evidence from high quality research to support the use of mathematics coaches (or "lead" teachers, as they may be called) for improving student achievement in mathematics. Mathematics coaches usually work with teachers of mathematics, not directly with students. However, there

is no evidence that those who now work as mathematics coaches are mathematically qualified for their positions, so it is possible that mathematically knowledgeable coaches are effective if studies can identify them. Further research is needed to determine whether mathematically knowledgeable coaches do help to improve student achievement.

IV.A. How to Strengthen Preparation Programs and Licensure Tests for Teachers of Mathematics in K-7

1. As noted in the Panel's report, the *mathematics coursework* of prospective elementary and middle school teachers should be strengthened. This recommendation has clear implications for the Commonwealth. As a consequence of a vote by the BESE in December 2006 to require prospective elementary and special education teachers to pass, as of January 2009, a 40-item mathematics licensure test, mathematics coursework may well be strengthened for these two groups of prospective teachers in the next few years. In fact, in July 2007, the Commissioner of Education issued Guidelines for the Mathematical Preparation of Elementary Teachers for preparation programs to use in strengthening their mathematics coursework requirements. The state should develop similar *guidelines for middle school mathematics teachers*. But we currently have no systematic information on the strength of the mathematics courses now taken by prospective middle school teachers of mathematics.[5]

2. As indicated in the Panel's report, teacher preparation programs and licensure tests for *early childhood teachers*, including all special education teachers at this level, should fully address what it calls the Critical Foundations of Algebra (the topics on whole numbers, fractions, and geometry, and measurement topics it lists for Grades K-7), as well as the concepts and skills leading to them. The legislature should fund an *independent analysis* by a mathematician and a mathematics educator of the mathematics coursework now required in these and other pre-service licensure programs and tests to determine how well their coursework and licensure tests address the Panel's recommendation and the new state guidelines.

3. As indicated in the Panel's report, teacher preparation programs and licensure tests for *elementary teachers*, including elementary-level special education teachers, should fully address all topics in the Critical Foundations of Algebra and those topics typically covered in an introductory Algebra I course.

4. Teacher preparation programs and licensure tests for *middle school teachers*, including middle school special education teachers, should fully address all topics in the Critical Foundations of Algebra and all of the Major Topics of School Algebra.

IV.B. How to Restructure Preparation Programs for Teachers of Mathematics in Grades 5-12

The Panel found no evidence of a relationship between conventional or traditional teacher preparation programs and student achievement. This finding implies that the state should be experimenting with and evaluating *alternative structures for teacher preparation that could increase student achievement*. Below are suggestions that take into account the findings of the Panel, other research studies, and my own experience in directing revisions of the Bay State's educator licensure regulations and teacher licensure tests when I served as senior associate commissioner in the Department of Elementary and Secondary Education from 1999 to 2003. These suggestions are based on ideas that I have elaborated in published essays and reports. Complete citation information is provided in the References section.

1. Prospective teachers of mathematics (and science) for Grades 5-12 should be prepared in licensure programs administered by mathematics (and science) departments *at both the undergraduate and graduate level*. For undergraduates planning to become mathematics teachers, *education courses should be field-based seminars linked to student teaching*, which should take place in the final semester of the senior year.

For college graduates or mid-career changers seeking to become mathematics teachers in grades 5-12, their preparation program could be a post-baccalaureate non-degree program or a master of arts in teaching (MAT) degree program. This preparation should include an *apprenticeship* in the schools as well as authentic mathematics coursework addressing the grade levels they seek to teach.

While prospective high school teachers could be expected to major in mathematics, prospective middle school teachers could be expected to complete a strong "minor" in mathematics.

2. Undergraduate *education courses should not be counted* toward an undergraduate or graduate degree for prospective mathematics or science teachers in Grades 5-12. Many prospective teachers end up taking one-fourth to one-half of their entire 120 credits towards a Bachelor of Arts (BA) or Bachelor of Science (BS) degree in education coursework. The Panel's report found no evidence that education coursework taken in teacher preparation programs helps to improve student achievement in mathematics (i.e., no relationship between certification and student achievement in mathematics).

3. MAT programs in mathematics should be *approved* (1) by the university's own internal procedures for master's degree programs in the arts and sciences, (2) by a professional organization for the discipline such as the American Mathematical Society, or (3) by the Teacher Education Accreditation Council in order to keep mathematics content at the center of the program. International standards as well as our own K-12 standards in mathematics should serve as one set of criteria to use in the accreditation of these MAT programs.

4. *Mathematics-specific pedagogical faculty* (ideally, effective teachers of mathematics) should be attached to each department offering a MAT program. Their home base should be the academic department. At department faculty meetings, they could report on the teaching or learning problems in that subject they encounter in Grades 5-12 classrooms. Those responsible for the content of the discipline and those responsible for the pedagogy together could then help prospective teachers work out content-relevant ways to address these problems through curriculum or through pedagogy.

5. Licensure programs should be developed for *full-time elementary mathematics teachers* (and full-time elementary science teachers). Elementary schools need incentives to reorganize staffing schedules to allow for full-time mathematics teachers, especially in Grades 5 and 6. They may be far more effective and economical than mathematics coaches, which add personnel and costs to school staff without evidence so far of demonstrable effect on student achievement.

Use of full-time elementary mathematics teachers also leads to much lower costs for professional development because there is no need to give all elementary teachers continuous professional development in mathematics, only those who teach it. As noted in the Panel's report, schools should carefully evaluate the use of full-time, well-trained elementary mathematics teachers. Some elementary schools in the state are piloting use of full-time elementary mathematics teachers (e.g., Boston's John Marshall Elementary School), but the results of evaluations are not yet available.

6. All *pedagogical training should take place in the classroom*, together with concurrent seminars led by the pedagogical adjunct faculty at the site. Student teachers should be evaluated by the cooperating teacher (who has demonstrated an understanding of both content and pedagogy), the principal or subject area supervisor, and supervisors from the mathematics department. *Recommendations for licensure* would be submitted to the state's licensing bureau by both the mathematics department and the school in which the student teacher apprenticed to assure joint accountability.

7. Whether or not programs for preparing prospective mathematics teachers for Grades 5-12 are centered in education schools or college mathematics departments, a *standard evaluation form* developed jointly by the licensing agency, mathematicians, and mathematics educators should be used for student teaching. At least one supervisor should be a member of the mathematics department at an accredited college or university.

IV.C. How to Restructure Preparation Programs for PreK-12 Teachers

We should consider training prospective teachers of *PreK-12 in this country in three-year pedagogical institutes*, as they are in most of the world. It is not necessary for preschool and kindergarten teachers, in particular, to complete an arts and sciences major in a four-year post-secondary education program in order to teach preschool or kindergarten. However, they should be academically competent high school graduates, as they are in other countries. In such an institute, education courses would focus on beginning reading, writing, and arithmetic pedagogy, and these prospective teachers would have to pass two academically demanding subject matter tests for licensure: in arithmetic and in reading instructional knowledge. If our current *undergraduate education schools could be restructured as three-year pedagogical institutes*, with their faculty accountable for children's achievement in literacy and numeracy in their graduates' classrooms, we would place accountability precisely where it belongs and start to reduce the deficiencies in those who teach the crucial beginning years of education.

IV.D. How to Strengthen Technology Education in Teacher Preparation Programs

1. All mathematics and science education faculty should be required to participate in a comprehensive *calculator-training program* designed for instructors of mathematics methods courses for elementary teachers, such as the program developed by Texas Instruments. Once methods courses provide models and training in the proper use of calculators for teaching elementary mathematics, new teachers will not need professional development in how to teach calculator use appropriately. Many teachers misuse them, according to testimony to the Panel by Richard Schaar, an executive at Texas Instruments.

2. Coursework in elementary, early childhood, and special education teacher licensure programs should show prospective teachers how to *use technology appropriately* in their teaching. These programs should be held accountable for providing this teaching to prospective teachers.

IV.E. Reform of Full Licensure and Renewable Contracts

1. Professional status (tenure), renewable five-year contracts, and full licensure should be available to new teachers after three years of frequent observations, evaluations, and a recommendation by a school supervisor—a process similar to the one used in British schools.

2. *Mentor programs* should be required in all schools. Those chosen to be mentors should be defined by the demonstrated ability to improve students' achievement in mathematics and pass an advanced test in the subject, such as the licensure tests in mathematics developed by the American Board for Certification of Teacher Excellence. Their training to be mentors should be funded and monitored by the DESE.

3. All mathematics teachers in Grades 5-12 should be required by the state to take at least *two authentic courses in mathematics for every five-year professional development cycle*. Each school district should determine what other professional development its teachers should take to meet local professional development requirements.

4. All *directors or supervisors of curriculum and instruction, coaches, and specialists in mathematics* should pass MTEL at the appropriate level and have strong qualifications (MS or Ph.D. degrees, or career experience in mathematics or a mathematical field). Similar requirements should apply to science.

IV.F. Licensure Reform

1. The second stage of the current two-stage licensure process-what is now called the *Professional license-should be eliminated,* and all teachers who achieve professional status (tenure) should be required to enter into their first five-year cycle of professional development.

2. Aspiring secondary mathematics (and science) teachers should be given the opportunity to receive a *provisional license* if they pass a demanding licensure test and the Criminal Offender Record Information (CORI) check, a school administrator is willing to hire them, and the school district can provide mentoring support. Schools must be free to hire provisional teachers in these areas. As a 2008 comparison of secondary teachers of math and science found (Xu, Hannaway, & Taylor), Teach For America teachers, who have little pedagogical training but strong academic credentials, were more effective as measured by scores on student end-of-course exams than experienced traditionally certified teachers. If the teacher is regularly evaluated by a subject matter supervisor as well as the high school principal, and receives positive evaluations over a three-year period of teaching, then the teacher should be granted a full license.

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Endnotes

[1] One peer-reviewed study suggests that excessive calculator use in K-12 may have negative effects at the college level. See W. Stephen Wilson and Daniel Naiman, "K-12 calculator usage and college grades," *Educational Studies in Mathematics*," 2004, 56, pp. 119-122. (http://www.math.jhu.edu/~wsw/ED/pubver.pdf).

[2] See, for example, David Klein, "A brief history of American K-12 mathematics education in the 20th century." In James Royer (ed), *Mathematical Cognition*, Information Age Publishing, 2002, pp. 175-225.

[3] I thank Ralph Raimi, Professor of Mathematics Emeritus, University of Rochester, for preparing this brief definition of school algebra.

[4] Massachusetts Department of Education, internal report, Course Progression and Placement Leading to Enrollment in Advanced Placement Calculus in the Twelfth Grade, March 2000.

[5] A report to be released on June 26, 2008, by the National Council on Teacher Quality, titled *No Common Denominator: The Preparation of Elementary Teachers in Mathematics by America's Education Schools*, by Julie Greenberg and Kate Walsh, will provide information on the topics covered in the elementary mathematics coursework currently required by 77 institutions in 49 states for prospective elementary teachers. The report found an enormous range in how twelve essential topics were covered in the nation's education schools. The report's major finding underscores the need for the new mathematics licensure test that will be required as of January 2009 for all prospective elementary and special education teachers in Massachusetts.

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