TOWARD EXCELLENCE IN K-8 MATHEMATICS

MATHEMATICAL SCIENCES EDUCATION BOARD

CENTER FOR SCIENCE, MATHEMATICS, AND ENGINEERING EDUCATION

NATIONAL RESEARCH COUNCIL

A letter report of the Mathematical Sciences Education Board, prepared for the National Science Foundation/U.S. Department of Education Interagency Working Group.

May 1997

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This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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(revised June 1997)

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INTRODUCTION

In his 1997 State of the Union Address, the President of the United States of America asked the Secretary of Education to develop a voluntary national test for individual eighth grade students, to be based on widely accepted, challenging national standards in mathematics. To support that endeavor, President Clinton directed the Secretary of the U.S. Department of Education and the Director of the National Science Foundation to form an interagency Working Group

> to develop an action strategy for using Federal resources to assist States and local school systems to prepare students to meet challenging math standards in the eighth grade, and for involving the mathematical, scientific, and technical communities in support of these efforts.
>
> The action strategy should include recommendations for the use of Federal resources to help States, local school districts, and schools improve teaching, upgrade curriculum, and integrate technology and high-quality instructional materials into the classroom, as well as motivate students and help them understand how math concepts are applied in the real world (Clinton, 1997).

The National Research Council (NRC) is charged to advise the Federal government in several areas. Situated in the NRC, the Mathematical Sciences Education Board (MSEB), with its close ties to all aspects of mathematical sciences education, has been asked by the Working Group to provide recommendations for the action strategy, in the following four areas:

- improving teaching through professional development and teacher preparation,
- accelerating the adoption and implementation of high-quality curriculum materials,
- integrating technology into the classroom, and
- building public support.

Given the MSEB's mission to promote high quality mathematics education, we are pleased to provide recommendations in the form of this report. We regard the eighth grade as a key point in the mathematics education experience. At this juncture, students make critical choices about their futures in mathematics, and their beliefs about their own potential are

solidifying. The mathematics community welcomes the focus on excellence in K-8 mathematics education that will be generated by the national test.

The MSEB has contributed several reports raising issues about mathematics education and standards in mathematics education, including *The Preparation of Teachers of Mathematics: Considerations and Challenges, A Letter Report* (National Research Council [NRC], 1996b), *Everybody Counts* (NRC, 1989), *Reshaping School Mathematics* (NRC, 1990), *Measuring What Counts* (NRC, 1993c), and *Measuring Up* (NRC, 1993b). The standards prepared by the National Council of Teachers of Mathematics—the *Curriculum and Evaluation Standards for School Mathematics* (National Council of Teachers of Mathematics [NCTM], 1989), the *Professional Standards for Teaching Mathematics* (NCTM, 1991), and the *Assessment Standards for School Mathematics* (NCTM, 1995)—constitute "widely accepted[1], challenging national standards in mathematics," and have been endorsed and promoted by the MSEB (NRC, 1989; NRC, 1993a).

The MSEB has not been asked to make comments directly about the proposed national test in mathematics. Nonetheless, the very existence of the Working Group coincides with the President's intention of having a voluntary eighth grade test. The action plan and strategies to be developed by the Working Group seem to be intended as the mechanisms for achieving excellence in mathematics education that will work in concert with the national test. Thus our recommendations are not generic recommendations about the improvement of mathematics education. Rather, they are recommendations that reflect the government's intention to institute a test, and to use that test as an occasion for improving mathematics education. Following the recommendations, we discuss the underlying considerations about the context in which the action strategy will be developed and undertaken.

RECOMMENDATIONS

This report begins with a set of overarching recommendations. Then, within the four specific areas under consideration by the Working Group, we provide recommendations, as requested, for the action strategy.

Overarching Recommendations

Construct and sustain a Federal effort that brings together, in a coherent framework for decision-making, the various National Science Foundation and U.S. Department of Education programs that will significantly influence K-8 mathematics education.

[1] The Third International Mathematics and Science Study (TIMSS) found that 95% of US teachers were either "very aware" or "aware" of current ideas about teaching and learning mathematics; 75% felt their teaching was in accord with current ideas. Weiss et al. (1994) find 56% of secondary school teachers aware of the NCTM *Standards* (Office of Educational Research and Improvement [OERI], 1997).

Such a coherent framework will ensure that the programmatic strategies can be effectively employed and related to the test itself. The means for enacting this recommendation are complex, and we urge the Working Group to consider questions such as: Could Title I funds be specifically allocated for the preparation and hiring of mathematics specialists in elementary and middle schools? Could some portion of Eisenhower dollars be reserved for providing long-term, school-based professional development for K-8 teachers? What about Goals 2000 dollars? Might there be a new program for the development of materials for use in school-based staff development that would progress in the directions indicated by the national mathematics test? Can the efforts of the School-to-Work program be aligned with efforts to promote high standards in grades K-8? How might Title V be reconceptualized to better prepare higher education faculty for standards-based mathematics education?

Devise a long-term plan (8-10 years, offset from political cycles) of interactive development involving test redesign and strategy adjustment, with ongoing monitoring and oversight.

An important first step in such a long-term plan is immediate Federal implementation of a process by which states and districts would be able to gather, along with student test data, information about the contexts in which students are learning mathematics, information about curriculum that is in place, information about the teachers' backgrounds and professional development activity, and information about classroom instructional practice and areas of content emphasis. It will be very difficult to interpret test results meaningfully, and to make constructive use of them, without a measure of what opportunities students have had to learn the mathematics that is being tested. Funding should be allocated to for the development of materials for the measurement of such contextual factors. Such tools could then be made available to states and districts. The report *Mathematics and Science Education Around the World* (NRC, 1996a) emphasizes the importance of linking contextual information to the interpretation of test scores, and methodologies for doing so are available in TIMSS (Schmidt et al., 1996; Stigler et al., in preparation), the National Assessment of Educational Progress (NAEP) and other sources. Without a federally orchestrated plan for gathering such information, using the test as any indicator of the effectiveness of various programs and approaches is impossible. Moreover, the accumulation and analysis of such data over time are essential to the process of test redesign and strategy adjustment.

Invest in a sustained agenda of basic research to better understand what mathematical thinking is, how to foster it through curricular choices and instructional practice, and how to support teachers in doing so.

The NCTM *Standards* call for increased focus on reasoning, problem solving, and making connections, and on mathematical processes such as conjecturing, proving, exploring, and analyzing. In addition, the reform documents recommend focus in content areas of mathematics that have not historically been part of the K-12 curriculum. The base of basic research that exists to support instructional practice and curriculum development in these areas is surprisingly meager. With the renewed attention that will be devoted to mathematics education through the national test and associated activity, the need for basic research that can guide the development and test the effectiveness of various approaches is not only timely, but critical if this

venture is to have a measurable impact. Particularly important is funding for basic research about instructional practice and teacher learning, and about the role of technology.

Recommendations for Improving Teaching

We recommend, for the next three years, a national focus on the professional development and preparation of grades 5-8 mathematics teachers to ensure that they are adequately prepared and supported to develop student learning at high levels.

Teachers of mathematics at the middle grades traditionally have borne the unique responsibility of helping their students in the transition from the arithmetic-dominated curriculum of the elementary years to readiness for the abstraction of algebra in the secondary school. With the advent of the NCTM *Standards*, new state frameworks, and new state-level eighth grade assessments, as well newly developed instructional materials, the mathematical responsibilities of these teachers have increased significantly. The recommended curricular topics for the middle grades now include a much greater emphasis on patterns and functions, algebra, and areas of statistics, probability, geometry, and measurement (NCTM, 1989). If the national test follows the NAEP framework, it is likely to also reflect these emphases.

At the same time that curricular demands are increasing, many states do not require certification or specialization at the middle grades[2]. The result is often that school districts employ either elementary teachers prepared for the elementary grades (K-6 or K-8), or teachers prepared for the secondary grades[3] (7-12). Neither the elementary nor the secondary preparation has consciously taken into account either the mathematical emphases that are particular to the middle grades, with its cross-disciplinary features and applications orientation, nor the special needs of middle grades learners. Few institutions of higher education actually offer middle grades specializations in mathematics, although such programs have been developed through NSF funding (Stake et al., 1993).

Teachers' professional development needs are substantial (Darling-Hammond & Cobb, 1995; National Center for Education Statistics [NCES], 1993). The introduction of the national test in mathematics will only heighten and intensify the need for immediate explicit focus at middle grades. A number of reports have emphasized the importance of strong and appropriate content preparation of teachers, such as the MSEB report, *The Preparation of Teachers of Mathematics: Considerations and Challenges* (NRC, 1996b). Introduction of the national test will make this recommendation even more critical.

To carry out this recommendation, it will be essential to:

[2] Thirty-four states offer middle grades certification, although several do not have specific requirements for mathematics (CCSSO, 1996).
[3] Nationally, only 63% of secondary school teachers hold a degree in the subject they teach (Education Week, January 22, 1997).

- **Build national, regional, and state accreditation and certification policies so teachers have the content knowledge and pedagogical expertise to support high standards in mathematics.**

  All states, over time, should strive to introduce middle school mathematics certification. Such certification should require knowledge and experience with mathematics and pedagogy appropriate to the middle school level. Such experiences would be consistent with the expectations of the National Board for Professional Teaching Standards and the Interstate New Teacher Assessment and Support Consortium. Within higher education, programs for preparing specialists in middle school mathematics teaching could become an integral part of all teacher education programs. In the short term, there should be a compilation of information on states with middle school mathematics certification programs. Such a compilation should include details about standards and relationship to school structure, as well as information about extant middle school mathematics teacher preparation programs in higher education.

- **Use and extend the research that clarifies how teachers' mathematics content knowledge relates to their classroom effectiveness, and how teachers can best learn about mathematics content.**

  In the long term, there is a need for increased funding for research about teachers' mathematics learning. More immediately, the NSF and U.S. Department of Education could jointly commission papers about the role of content knowledge in teaching effectiveness and disseminate them widely to teacher preparation institutions.

- **Enhance mathematics professional development experiences for preservice and inservice middle grades mathematics teachers.**

  In the long term, this goal can be accomplished by fostering partnerships among mathematicians, mathematics educators, and teachers that focus on the mathematical emphases and instructional issues of the middle grades curriculum. In the short term, the NSF and the U.S. Department of Education could sponsor a National Professional Development Forum centered on various middle school curriculum materials. There are several types of materials and curricula now available at the middle grades, and teachers need to become familiar with the options, learn from those who have used these materials about what is involved in their successful implementation, and examine the evaluation findings from these projects. It is also important to understand better the shortcomings of such materials. There is growing evidence that curriculum-based professional development—i.e., professional development situated concretely in the student curriculum—correlates significantly with teacher effectiveness (Cohen & Hill, 1997).

  Teachers' opportunity to learn needs to be grounded in practice (NRC, 1996b). By examining and analyzing student work, teachers come to develop shared expectations for student performance. Any national test should be accompanied by a guide for teachers that includes the content framework, sample items, student responses, sample rubrics, and

teaching strategies. Such a guide should be disseminated over the Internet, as a means of generating conversations and professional networking. Additional professional development could be centered around helping teachers understand the nature and scoring of extended response items.

For the proposed national test to be a useful tool, it must be set in a broader assessment context that includes classroom assessment consonant with it, and with the K-8 reforms. Considerable staff development efforts educating teachers about assessment will be necessary, and have been undertaken elsewhere (Stake & Raizen, 1997).

- **Engage the mathematics higher education community more centrally in providing high quality preparation and professional development experiences for K-8 teachers of mathematics.**

In the long term, this could involve linking all mathematics teacher development to appropriate content-based programs in colleges and universities. In the short term, postsecondary mathematics faculty need opportunities for professional development where they can learn about K-8 mathematics education and how the mathematical content areas recommended for grades K-8 are typically treated through curriculum and instruction. Higher education faculty also could benefit from a focus on the issues in teaching content effectively to prospective and inservice teachers. A first step would be to compile examples of programs and materials used for helping teachers learn mathematics and mathematics teaching. These could be disseminated and reviewed with postsecondary mathematics faculty as well as K-12 professional development practitioners, through conferences or other national networking activities.

Recommendations about the Adoption and Implementation of High-Quality Curriculum Materials

We recommend that high-quality instructional materials and associated support mechanisms be available for all schools and for those who prepare and provide professional development for teachers.

Federal agencies should focus attention and resources on raising awareness and facilitating implementation of standards-based curricula in topic areas to be emphasized in the national mathematics test. Since the publication of the NCTM *Curriculum and Evaluation Standards* in 1989, commercial publishers as well as the Federal government have engaged in substantial instructional development activities, often designed to reflect the emphases of the *Standards*. Many of these materials are just now becoming widely available. Issues related to mathematics curriculum at the middle grades are complex, as reflected in the diversity of curriculum designs at this level. There are new, innovative materials that are module-based, where teachers and students work on large, cross-cutting themes over extended periods, often with a technology emphasis. There is also a strong movement toward preparing all students to take an algebra course in the eighth or ninth grade; and there is the more typical seventh and

eighth grade sequence emphasizing general topics and culminating in pre-algebra ideas. This array of choices and competing directions places teachers in the difficult position of making judgments and decisions without adequate data or information about the effects of such choices, or the long term impact on student learning and mathematical progress.

To carry out this recommendation, it will be essential to:

- **Provide guidance to those who make curriculum selections—guidance in judging the quality of materials, and guidance which includes information about the conditions and context under which the materials have been used by others, and the resulting student achievement.**

  In the long term, there is a need to support ongoing implementation research and revision of curriculum based on teachers' and students' experiences. Such research and revision should be coordinated and linked to shifts in the national test and its emphases. The "National Professional Development Forum" mentioned earlier could provide in-depth looks at curriculum, to help people in all schools understand how these materials work and their relationship to the national test. Heightened efforts to disseminate curricular materials and evaluation information should begin immediately. Discussion of the ways in which the classroom assessment tools within these materials will complement the national test, as teachers judge student performance, needs to be introduced.

- **Help administrators, school board members, teachers, and the public understand the relationship of curriculum materials to the emphases on better student preparation in mathematics.**

  The kinds of learning this test will measure will be unevenly available to children in the United States. Mathematics teaching and learning should be structured so that all students are given the opportunity to achieve at their maximum potential. School leaders must recognize what is at stake in their decisions about adoption of instructional materials, professional development, and resources for school mathematics. Districts will need to consider how their resources can ensure that all students have the educational opportunities that will enable them to increase their capabilities in mathematics. Most immediately, there is a need to examine the potential relationship between the national test and the emphases in various curriculum materials. It will be important to have an organized program to reach administrators, especially principals and superintendents, to guarantee that they understand the high standards for students in grades K-8 set forth by the national test, and the implications for their students of various curricular choices.

- **Provide curriculum materials for use in teacher preparation and development and for use by higher education faculty and staff development professionals.**

  There is no coherent or nationally recognized system for reviewing, publishing, sharing, and critiquing the curriculum materials that are used to help teachers learn. Higher education faculty and professional developers frequently create their own materials. Higher education

mathematics faculty responsible for teaching mathematics content to prospective elementary and middle grades teachers need access to appropriate high-quality materials. Staff developers who offer long-term workshops in schools need new materials that focus on the important mathematics of the K-8 grades. In the short term, prototype course modules in mathematics content for use with prospective teachers at undergraduate institutions should be developed and disseminated to faculty in mathematics departments via the Internet and a national colloquium. Similarly, appropriate materials for inservice teacher development should be selected or developed and disseminated for school-based leaders in mathematics education, with involvement by the mathematics teacher professional organizations.

Recommendations for Integrating Technology into the Classroom

We recommend that technology be made available on an equitable basis for use in improving student learning and enhancing teacher professional development.

Technology includes computers, calculators, and other learning tools that can help students with a diversity of learning needs and preferences. In addition, technological tools provide teachers with an enhanced array of strategies for instruction. Research indicates some promising uses of technology as a means of helping learners understand mathematics concepts more deeply and effectively (Heid, 1988; Hembree & Dessart, 1986), and continued research into the pedagogical implications of various uses of new technology is needed. Such instructional use of technology, to be effective, requires appropriate subject matter understanding on the part of teachers.

A key step here will be for the Federal government to follow through as soon as possible with its commitment to make the Internet available to all schools. The Internet has potential value for networking students and teachers, and for dissemination of educationally valuable materials. At a different level, the technological opportunities for teacher learning, for professional collaboration, and for building of networks around professional interests are burgeoning and promise an end to the traditional isolation of teachers. Literature in professional development is quite clear on the benefits of providing professional development opportunities within a support community (Lord, 1994).

To carry out this recommendation, it will be essential to:

- **Enable teachers to establish contacts for mentoring, participate in networks, and access a variety of curricular and pedagogical models, via technology.**

  Over the long term, increased research about how teacher learning and development occurs through innovative technologies will be critical to using these resources most effectively. In the short term, expecting all federally-funded teacher enhancement and professional development programs to have an Internet component would be useful.

- **Provide all students with access to appropriate technologies for learning mathematics.**

All federally funded programs for pre-school and K-8 students should include an appropriate introduction to the effective use of calculators and other technology. The national test should be constructed to include the judicious use of calculators. In this way the test can focus on higher-order conceptual understanding. This might also help ensure that technology is made available widely in the middle grades. In the short term, synthesis and dissemination of existing research and examples about the promising uses of the World Wide Web, the Internet, and other technologies for enhancing mathematics education should be assembled and disseminated widely. Models are needed by parents, teachers, and students for productively using test items to improve mathematics learning.

Recommendations for Building Public Support

We recommend that public information efforts highlight the linkages between the national test and the associated action plan, in order to mobilize the general public and the mathematics community to understand the entire process.

In particular, the public, the business community, and the mathematics community need to understand how any national test might be used as a vehicle for improving mathematics education. It is likely that the public will measure the effectiveness of the action plan strategies by progress on the proposed national test. Any test explicitly intended to promote improvement in student learning and in mathematics education more generally is not as familiar to the public as a test designed to measure the status quo. Such a test would be an indicator of "what ought to be" rather than "what is." Helping the public understand the complexity and enormity of change and improvement, on a time frame they will tolerate, is challenging.

To carry out this recommendation, it will be essential to:

- **Organize immediately a public information effort, managed by a consortium of mathematics and mathematics education organizations and an experienced public information firm, to design and implement a program introducing and promoting the importance of high standards in K-8 mathematics.**

  This effort could extend the experiences that the National Council of Teachers of Mathematics and the Joint Policy Board for Mathematics have had in the areas of public information. A major goal would be to influence public opinion about the need for a significant mathematics experience for all students through grade eight, and to explain how a national test could promote this goal. New curriculum materials and standards-like goals need to be part of the public awareness, as well as information about the various purposes and types of assessment. Considerations about how to motivate students to see this test as important are crucial. This effort should also highlight the importance of mathematics in applications, the beauty of mathematics as a field, and the role of mathematics as a gateway to careers and to higher education.

Over the long term, schools could function as community centers with extracurricular programs centered on the mathematical emphasis of the national test. Such activity might have the wider impact of promoting academic achievement in all areas by helping students develop social networks in which academic success is valued.

- **Mobilize the mathematics community in its understanding and support of K-12 mathematics education, in light of the new context provided by the national test.**

In the short term, the National Science Foundation and other funders should make clear, through their program criteria and announcement, their expectation that, whenever appropriate, mathematics faculty and departments should exhibit commitment to and engagement in the improvement of K-12 mathematics education—as something essential to their own self interest. Also, when possible, all federally funded programs that address issues in mathematics education should involve broad representation of professionals from the mathematical sciences, to include academic and industrial mathematicians and mathematics educators.

UNDERLYING CONSIDERATIONS

The following considerations about the context in which the action strategy will be developed and undertaken were fundamental to the MSEB discussions that are the basis for this report.

We assume that the action strategy developed by the Working Group will build on current efforts. The established activity to improve mathematics education that has been built through the National Council of Teachers of Mathematics, the initiatives supported by the National Science Foundation and the U. S. Department of Education, as well as many private foundations, together with the many excellent efforts initiated at the state and local school level, should serve as the base and inspiration for this renewed effort to improve mathematics education. These efforts are consistent with the reforms advocated in the NRC reports *Reshaping School Mathematics* (NRC, 1990) and *Everybody Counts* (NRC, 1989). In particular, much is to be learned from situations where assessments have been used as the lever for improved mathematics education (such as in the states of Connecticut and Texas). The notion of using assessment as a means of supporting good instructional practice is central in the NRC report *Measuring What Counts* (NRC, 1993c). Those individuals and groups who have been working to develop standards-based curricula will also have much to contribute to the action strategy design and implementation.

Secondly, many of our recommendations for the action strategy are based on the expectation that the national test in mathematics will be consistent with current thinking of experts in mathematics assessment (NCTM, 1995; NRC, 1993c). The MSEB document, *Measuring What Counts* (NRC, 1993c), provides three principles for assessment which, if upheld in the national test, would also provide direction for the associated action strategy. These are: "The Content Principle: assessment should reflect the mathematics that is most important for

students to learn. The Learning Principle: assessment should enhance mathematics learning and support good instructional practice. The Equity Principle: assessment should support every student's opportunity to learn important mathematics" (NRC, 1993c, p. 1).

Finally, in order for the proposals for the action strategy to be effective, we assume that the national test in mathematics will convey to students, teachers, and the public a set of high expectations to aspire to in K-8 mathematics. This would mean that the content emphases and coverage of the national test will be consistent with mathematical emphases that are valued in the mathematics and mathematics education communities (NCTM, 1989; NRC, 1990). Because the action strategy will involve teachers and the public, the content emphases and coverage of the national test need to be made explicit and distributed widely, so that teachers, parents, and students will be constructively guided in their local curricular decisions in grades K-8, and in local planning for continuing professional development of teachers. In helping the public to understand the test and the action strategy, the test needs to be presented as a means of focusing on the important mathematical goals of the K-8 grades, and as an initial indicator, not a final grade, of students' progress toward those goals. We assume also that the test can be refined and adapted over time to reflect the mathematics community's changing values about assessment practices, about what mathematics students should know and be able to do, and about the effectiveness of the action strategy.

It is also our understanding and urging that the mathematics and mathematics education communities will continue to have substantial opportunity to be involved in influential roles throughout the entire process of decision making about test development, implementation, and evaluation. The MSEB will seek ways of facilitating and ensuring this ongoing involvement.

CONCLUSION

The proposal for a national test of mathematics and the actions associated with that proposal present an opportunity for unprecedented focus on the mathematics experiences of children in grades K through eight. The eighth grade year is a significant one, in that for many students it includes the beginning of their formal study of algebra, a gateway to secondary school mathematics. Of particular importance is the potential for a broad base of support to improve mathematics education, in the areas of teacher professional development, curriculum, technology, and public awareness. These activities represent a unique opportunity for the mathematics and mathematics education communities to undertake concerted and bold efforts toward excellence in mathematics learning for all children.

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