Chapter Five

TOWARD A PARTNERSHIP BETWEEN GOVERNMENT AND THE MATHEMATICS EDUCATION RESEARCH COMMUNITY

Implementing the research and development program discussed in the previous three chapters will require forging a new partnership between the federal government and researchers and practitioners. Producing cumulative and usable knowledge related to mathematical proficiency and its equitable attainment will require the combined effort of mathematicians, researchers, developers, practitioners, and funding agencies. In this venture, the federal funding agencies, particularly the Office of Educational Research and Improvement (OERI), must take the lead. It is the leaders of the funding agencies who must make the case for the resources needed to implement the program described in this report. But beyond that, these funding agency leaders must also take the steps necessary to shape a funding and research and development infrastructure capable of carrying out this program.

In this chapter, we begin with some general observations about the qualities of the program that we envision. We then outline activities needed to carry out high-quality work that is strategic, cumulative, and useful. Finally, we suggest initial steps in creating the program.

THE NATURE OF THE PROPOSED PROGRAM OF RESEARCH AND DEVELOPMENT

The work proposed in this report fits into three broad classes of research and development activities:[1]

The first class comprises *descriptive studies* using appropriate and replicable methods to identify and define important aspects of mathematics learning and teaching. Such work would deal with key aspects of understanding and perfor-

[1]In framing these categories of activities, we drew heavily on concepts developed by the National Research Council Committee on Scientific Principles for Education Research (Shavelson & Towne, 2002). However, that committee did not extensively consider development, an important component of our third class of activities.

mance. Of interest would be changes in understanding and performance over time, associations and correlations across levels of schooling, and the connections among the phenomena of mathematics learning and instruction and the characteristics of students, teachers, and school systems. Studies in this area might include design experiments in which researchers actively create an intervention and study its effects in a specific setting. Taken together, such studies provide a basis for generating hypotheses, models, and theories about how mathematics learning and instruction work and about what might be done to improve it.

The second class of activities includes *research designed to develop and test models to explain the phenomena described in studies of the first type* using methods that support the attribution of causal relationships and allow identification of the processes and mechanisms that explain these causal relationships. These methods should deal appropriately and rigorously with the problem of ruling out alternative explanations for findings. This may be done through the use of experimental methods and randomization, but in cases where such methods are not feasible, researchers must pay careful attention to questions of how well their methods deal with potential threats to the validity of the conclusions drawn, given the particular purposes of the study.

The last class of work is *design and development* to produce knowledge, curricula, materials, tools, and tests that can actually be used in practice in particular situations. This design and development work ought to be based on the explanatory efforts and the hypotheses and theories identified and established in the first and second classes of activities. However, in most cases, such work will need to go beyond these two classes of research because the research will not be completely adequate to support the particular design. These design and development efforts should include appropriate and rigorous studies intended to establish whether or not the designs work, how well they work compared with other approaches, and the probability that they will work under specified conditions and in specified settings (including evidence on whether and how they work "at scale").

Such design and development work inevitably will generate problems, questions, and insights that will support, motivate, and inform work of the first two types. For example, an important line of research is the comparative study of different curriculum materials. Another is the design and comparison of alternative approaches to professional development.

The RAND Mathematics Study Panel advocates placing significant emphasis on this third class of activities. The creation of materials, tools, and processes that can be widely used in mathematics education is an important component of a problem-centered program of research and development. In fields such as medicine, agriculture, and computer science, this type of research-based development is key to advances in the technologies of each practice. For example, when a researcher discovers some molecular process in cell proteins, the public does not ask why practicing doctors are not utilizing the new knowledge. Instead, the vast public and private development infrastructure incorporates the new knowledge into its development programs. A new medicine or a new use of an existing treatment might result. At this point, when knowledge becomes a new technology, research can be directed to how doctors are using the new medicine and with what effect.

Such development programs in education will involve people with skills that are analogous to those of engineers in industrial sectors. The programs will typically also involve close collaboration with the users of the products—i.e., practitioners and policymakers. If properly carried out, these development efforts will also yield important insights concerning the scalability of interventions, the effects of various school contexts on the outcomes of an intervention, and requirements for effective implementation of a program or intervention. Some components of these development efforts may take the form of *problem-solving research and development* recently proposed by the National Academy of Education.[2]

Over time, OERI and other funders will need to consider the most appropriate means of supporting design and development. In other sectors of the economy, most development is carried out by the private rather than public sector. Increasingly, however, partnerships between researchers in universities and private profit-making and nonprofit organizations have become important. The proportion of the proposed program's resources devoted to research-based development will depend upon evolving decisions concerning the division of development responsibilities between the public and private sectors, as well as the promise of proposals for development. What we describe here represents a major change from the status quo of research enterprises in universities and research firms and will require the active support of program leadership.

A vital program of mathematics education research and development should include a variety of research and development activities. Figure 5.1 offers a schematic view of the proposed program's design. Some activities in each of the cells would be funded at the start of the program. Because each of the focal areas is important to the program's goals, we make no recommendation concerning the relative levels of funding for each of the areas. Instead, we expect those

[2]See National Academy of Education, 1999, and Sabelli & Dede, 2001.

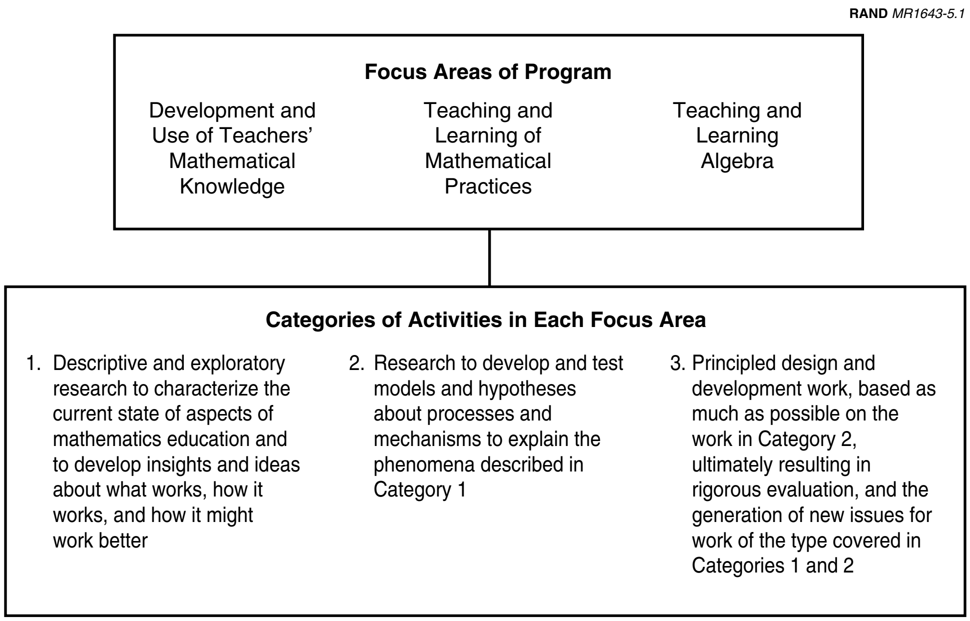

Figure 5.1—Components of the Proposed Mathematics Education Research and Development Program

levels would be determined initially by the relative quality of the proposals submitted in the various areas.

However, as the program evolves through time, judgments will need to be made concerning the contributions that work in each area can make toward the goals of the program. Based on these judgments, funders will want to take actions to shape the balance of emphases in the program. Moreover, we expect that design and development (the third category of activities) will require increasing proportions of the total program funding as the program moves forward due to the cost of doing research-based development. In a subsequent section, we describe a mechanism for making judgments about the allocation of resources among these activities.

CRITERIA FOR THE QUALITY OF THE RESEARCH AND DEVELOPMENT PROGRAM

Articulating explicit criteria for the quality of the research and development program is important to ensure that the program meets high standards of rigor and usefulness. Criteria related to these standards would likely evolve as the program grows and changes. One set of criteria that appears crucial from the start deals with the selection, design, and conduct of program projects and initiatives. A second set of criteria concerns the kinds of communication, sharing, and critiquing vital to building high-quality knowledge-based and evidence-based resources for practice.[3]

With respect to the first set of criteria, the research and development program should *respond to pressing practical needs*. Improvement in the knowledge of mathematics for teaching, the teaching and learning of mathematical practices, and learning of algebra are all areas of practical need in which significant research questions can be investigated and research-based development efforts can be fruitful. Advanced mathematics is a gatekeeper in today's society, setting an entrance requirement for access to further education and economic opportunity while disproportionately creating barriers for students of color and students living in poverty. Thus, the research and development program should hold promise for promoting equitable practices in the teaching and learning of algebra.

In addition to being responsive to the needs of the practice community, the program should *build on existing research* wherever possible. The program should be cumulative, building on what is useful and proven and discarding lines of inquiry that have been shown to be unproductive.

An effective research and development program should also *be linked to relevant theory*. While a goal of research over the long term is to generate new knowledge, often in the form of new theories that provide explanatory and predictive power, scientific inquiry must be rooted in and guided by existing theoretical or conceptual frameworks. Development efforts should also be theoretically grounded. Although the goal of a principled design and development effort may be to create tools and program designs, theoretical or conceptual frames should drive the choices developers make—for example, in the inclusion and sequencing of particular algebraic concepts and skills in curriculum development. Similarly, researchers should use existing theories and conceptual frames as they make decisions about the types of evidence needed to support, refute, or refine their hypotheses.

To that end, the *methods a researcher uses should be appropriate for investigation of the chosen question* and reflect the theoretical stance taken. As Shavelson & Towne (2002) stated:

> Methods can only be judged in terms of their appropriateness and effectiveness in addressing a particular research question. Moreover, scientific claims are significantly strengthened when they are subject to testing by multiple methods. While appropriate methodology is important for individual studies, it also

[3]Again, in putting forth these criteria, we acknowledge our debt to the work of the NRC Committee on Scientific Principles in Education Research (Shavelson & Towne, 2002).

> has a larger aspect. Particular research designs and methods are suited for specific kinds of investigations and questions, but can rarely illuminate all the questions and issues in a line of inquiry. Therefore, very different methodological approaches must often be used in various parts of a series of related studies.

A coordinated program of research and development would support groups of researchers to investigate significant questions from different theoretical and conceptual frames using methods consistent with both the questions and these frames.

A further criterion for a high-quality coordinated program of research and development is that the *findings of researchers and developers are regularly synthesized.* The use of common measures of independent and dependent variables across studies, where appropriate, will facilitate syntheses. The results of syntheses help to frame new research questions that seek to resolve inconsistent findings, address missing areas, replicate and generalize the results, and test interventions that are a result of research-based development. Synthesis work strengthens the validity of knowledge generated and enhances its usefulness and the usefulness of the products developed from that knowledge. To support syntheses, replication of results, and generalization of results to other settings, researchers and developers must *make their findings public and available for critique* through broad dissemination to appropriate research, development, and practice communities.

The program we envision would also support a *dynamic interchange between research and development* as progress in one area influences the other in a reciprocal fashion. Developers seeking to solve problems need to draw upon and, on occasion, carry out research to meet their objectives. Development, and the evaluation of development, will frequently raise questions that should be explored in new research.

In order to carefully scrutinize and critique the work of researchers and developers and begin to use the results of their work, the research and development community must have access to *an explicit and coherent explanation of the chains of reasoning that lead from empirical evidence to inferences*. A coordinated program of research and development requires detailed explanations of the procedures and methods of analysis used in collecting and examining empirical evidence. Additionally, developers should make explicit the evidence-based rationale for the choices made in development. This information should be available to the appropriate audiences, particularly the practitioners who use the products.

Developing a program possessing the qualities enumerated above would build a "culture of science" such as that recently described and advocated by the Committee on Scientific Principles for Education Research of the National Research Council. The RAND Mathematics Study Panel is aiming for a program characterized by such a culture coupled with an intimate connection with practice that facilitates effective use of the knowledge and other products produced by the program. The details of such a program are set forth in the next section.

AN ORGANIZATIONAL STRUCTURE TO CARRY OUT THE WORK

The criteria we discuss in the previous section strongly suggest that a coordinated, cumulative, and problem-centered program of research and development in mathematics would require skilled management and direction.[4] The focus on cumulativeness and rigor requires that government funders, as well as performers in the field, approach and manage their work differently than they have in the past. The exact nature of this management will evolve as the work unfolds and will depend on the size of the program.

The next several subsections describe a structure that might emerge over time. The structure consists of an overarching Mathematics Education Research Panel (which we discuss further at the end of this section) with support from three smaller Focus Area Panels for each of the three focus areas proposed in Chapters Two, Three, and Four. Finally, each focus area would ultimately be assisted by a Focus Area Center that would convene groups of researchers and practitioners concerned with the focal area, carry out periodic syntheses of work, and support both the government program offices and the panels.

Collectively, these efforts are intended to advance the cumulativeness and scientific quality of the program and promote the use of knowledge and products the program develops. The structure we propose is likely to be too elaborate for funding levels and activities in the initial year or two of the program. However, the description provides our sense of how a cooperative and coordinated program of research and development in mathematics education might be run as it gains size.

Focus Area Panels

One way in which the program might ultimately be organized is shown in Figure 5.2. We propose that the program be organized according to the three focus

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[4]As of this writing, OERI is in the process of being reauthorized, and its organization is likely to change. Moreover, there appears to be increasing use of joint programs, such as the Interagency Education Research Initiative that coordinates funding from OERI, National Science Foundation, and National Institutes of Health, in an effort to capitalize on the strengths of each agency. The organization proposal suggested in this chapter, which is based on the current OERI structure, would need to be tailored to future organizational and funding situations.

areas that the RAND panel has identified. For each focus area, a standing panel would be created. These panels would have three important roles. They would (1) advise OERI and other funders on priorities and guidance to be included in Requests for Applications, as well as (2) suggest criteria by which to judge the quality of proposals and provide recommendations for expert peer reviewers to OERI and other funders. Periodically, the panels also would (3) analyze and interpret the yield of the work in the focus areas and carry out planning exercises extending and revising the plans that exist for each focus area. Their work would be advisory. OERI and other funding agencies would manage the actual peer review of proposals.

The panels shown in Figure 5.2 constitute a major means for fostering the coordinated action proposed in this report. The government would appoint the panels, and their members would have staggered terms in order to promote continuity. The membership of the panels should represent a wide range of viewpoints, including those of mathematics education researchers, mathematicians, mathematics educators, cognitive scientists, developer/engineers, experts in measurement, and policymakers. As we note later in this chapter, each panel will be assisted in its work by a Focus Area Center.

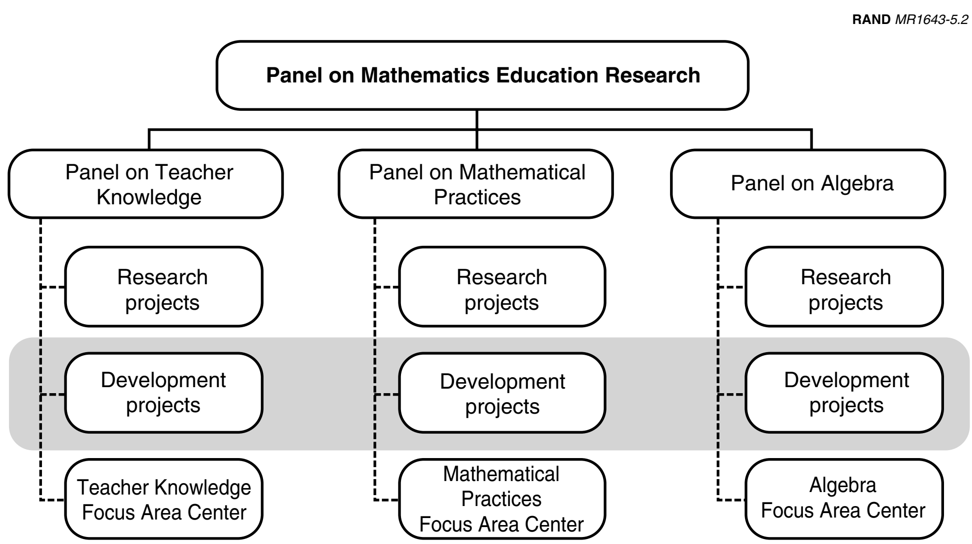

Figure 5.2—Major Activities in the Proposed Mathematics Education Research and Development Program

Activities in Each Focus Area

The trio of boxes under each panel box in Figure 5.2 denotes the major classes of activities within the program. The meaning of the top two is obvious; they are the research and development projects that make up the program. (The shaded area indicates that development projects often cross over focus areas.) The third class of activity, located in the Focus Area Centers, involves a number of functions to promote and support this cooperative and coordinated research and development effort. For example, a center would carry out periodic research syntheses. It would convene leaders of funded research and development projects to discuss ongoing work and crosscutting and comparative results. It might serve as a means for coordinating the development of common measures to foster the comparison of research findings and replication of research results. Finally, a center might provide various "contracted out" functions in support of OERI's management of the program.

The Focus Area Centers would be jointly supervised by the appropriate Focus Area Panel and personnel from the funding agencies. The centers would be selected on the basis of a targeted competition.

The Role of the Panel on Mathematics Education Research

As the program evolves, it will be important to carry out efforts seeking to make collective sense out of the work being supported in the various focus areas. We propose that this function be the responsibility of a Panel on Mathematics Education Research. In carrying out its duties, this comprehensive panel would work closely with the Focus Area Panels under it and the Focus Area Panels' respective centers. If sufficient resources become available, the panel might propose additional focus areas that should be added to the work being carried out in the three focus areas. It might also propose research-based development programs that span the focus areas. The Panel on Mathematics Education Research would advise OERI and other funders concerning improved policies relating to the management of the program and ways to promote effective use of the results of the program's work. Finally, as with any research and development enterprise, carrying out a comprehensive program review every three to five years is imperative. This would be a responsibility of the Panel on Mathematics Education Research.

Whereas the RAND Mathematics Study Panel proposes that the Focus Area Panels be made up largely of individuals with expertise in research, development, or practice, the Panel on Mathematics Education Research should have a broader membership. While we recommend the panel have strong representation from the research community, its membership should also include policymakers, members of the business and professional communities, and others with a strong concern for the quality of mathematics education. As with the Focus Area Panels, this panel would be appointed by and advise OERI. The Panel on Mathematics Education Research, with support from the Focus Area Centers, should publish a biennial report on the progress of the program.[5]

THE ROLE OF OERI IN CONDUCTING PRACTICE-CENTERED RESEARCH AND DEVELOPMENT

As of this writing, Congress is considering the reauthorization of OERI. The exact form of the reauthorized agency is unknown, but it seems clear that many members of Congress seek a stronger and more rigorous program of education research that embodies the features of good science. The RAND Mathematics Study Panel strongly supports such a goal. Our suggestions concerning OERI's role in the program are motivated by this goal.

In mounting a program of mathematics education research and development, OERI and its successor agency have several crucial roles to play. In particular, they should:

- Provide active overall leadership for the mathematics education research and development program
- Manage the processes of solicitation and selection of research and development projects and programs in a way that promotes work of high scientific quality and usefulness consistent with the principles outlined in this chapter
- Work in ways that build both the quality and extent of the infrastructure within which the research and development in mathematics education are carried out.

We treat each of these roles briefly in turn.

Leadership

Perhaps the most critical function that OERI must play is to provide leadership to the collective effort proposed in this report. Although we have recommended a set of panels to advise and assist OERI, panels are seldom able to lead. Pro-

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[5]The pending reauthorization of OERI may well make new provisions for an advisory and/or governing board for the agency. It is conceivable that the substantive review and planning of the agency's high-priority research and development, which we suggest should be assigned to a Panel on Mathematics Education Research, could instead be assigned to a subcommittee of such a panel (which presumably would also have business, professional, and policymaker representation). It would be important to avoid unnecessary duplication of these functions.

gram managers (and supporting staff) are needed who are willing and able to make decisions concerning program strategy, create a culture within OERI emphasizing excellence in research and development, and represent the program to superiors in government and to Congress. They should have both the capability and the time to be substantively involved with the work of the program. The leaders should be able to gain the confidence of and work with both researchers and educators. Our panel's view on this echoes that of the National Research Council's Committee on Scientific Principles for Education Research, whose first design principle for fostering high-qualitative scientific work in a federal education research agency is to "staff the agency with people skilled in science, leadership, and management."[6]

Historically, it has been difficult to recruit such staff to OERI. In part, this difficulty reflects the agency's reputation as a place where it is difficult to do good work. Probably more important is the fact that the agency had little funding to carry out work of the scope and quality that the RAND panel is proposing. We recommend that the leadership of OERI make explicit efforts to create positions and working conditions that will be attractive to the kinds of people capable of leading and managing the program we propose. But OERI cannot do this by itself. Senior people in the mathematics education research field have an obligation to help OERI by encouraging their talented junior colleagues to spend time in OERI and by supporting the OERI staff through active and constructive participation in the peer review and advisory processes.

Managing for High Scientific Quality and Usefulness

A cornerstone of good management in a research and development funding agency is an effective process for ensuring the quality of the work that is supported. Creating an effective peer review system that involves individuals with high levels of expertise in the subjects and research methods of concern is crucial. A peer review system that has the confidence of the field and of the scientific community is likely to attract high-quality researchers and provide reasonable assurance that quality proposals are supported. While the RAND panel advocates a system for effective peer review that possesses some continuity in the reviewers from funding cycle to funding cycle, we have not examined the administrative requirements of OERI in sufficient detail to recommend specifics concerning the management of the peer review system.

The Panel on Mathematics Education Research and the three focus area panels that we propose are not intended to be part of the peer review process in the selection of proposals. Individual members of these panels might serve as peer

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[6]Shavelson & Towne, 2002, p. 7.

reviewers. However, these standing panels do have important roles to play in the quality assurance process. In their role of synthesizing the research, they will have the opportunity to review the quality of the work that has been supported by the program and advise OERI concerning this quality.

The Focus Area Panels also play another potential role in promoting the scientific quality of the program. They should identify areas where replication of research findings should be sought or where work examining possible alternative explanations for research findings should be encouraged. In short, the panels could play an important role in creating the culture of scientific inquiry that is necessary to the success of the program.

Finally, OERI should emulate the National Institutes of Health (NIH) and parts of the National Science Foundation (NSF) in using the results of peer reviews to help unsuccessful applicants for grants to improve and resubmit proposals that are worthy of support. Working with the applicants is another way in which the OERI program staff can be substantively involved with the program and in which peer review can be used to improve the quality of work in the program.

Concern for Enhancing the Research and Development Infrastructure

We agree with the National Research Council's Committee on Scientific Principles for Education Research that investment in the research infrastructure will be an important contributor to the quality of an effective program of research and development.[7] We go beyond that committee's recommendations to emphasize the importance of an infrastructure that supports the research-based development and scaling of research findings that we see as being important to the improvement of practice.

OERI can enhance the infrastructure for research and development in a number of ways:

- As an early step in developing a mathematics education research and development program, OERI should consider a special effort to assemble and, where necessary, develop measurement instruments and technology that could be widely used by researchers, and thus enhance the opportunities for comparing and contrasting findings of various research efforts.
- OERI should be prepared to create or enhance institutions for carrying out mathematics education research and development where a clear need and function can be demonstrated. The commissioning of the Focus Area Centers suggested earlier would be an example of such institution building.

[7]Shavelson & Towne, 2002.

- OERI solicitations associated with a mathematics education research and development program should include encouragement for the training and mentoring of young scholars as a means of attracting new people to the field.

Communications among researchers in the field should be enhanced through the activities of the proposed panels. In producing this report, for example, the widespread review and discussion of the first draft was invaluable. Open discussion and critique contribute to the development of the field. Advancement of science depends on open debate unconstrained by orthodoxies and political agendas. To promote this discussion and critique, the composition of the panels and the extended research communities must include individuals with critical perspectives.

While these suggestions are specific, they are part of a more general recommendation that OERI should take responsibility for developing an infrastructure that will improve the quality of research and development in mathematics education and strengthen the research field's capacity to engage in high-quality work.

INITIAL STEPS IN IMPLEMENTING THE PROPOSED PROGRAM

The proposed program is ambitious and strategic. Based on hypotheses about the areas in which investments will yield high payoffs for increasing the mathematical proficiency of all students, the program places great value on scientific rigor and the usability of the knowledge produced. However, the recommendations will bear fruit only if the president and Congress are willing to significantly increase the level of spending on mathematics research and development. Assuming that a promise of such funding exists, where should OERI start?

The RAND panel recommends that a mathematics education research and development program begin with two important efforts:

- A research solicitation structured around the three focus areas discussed above
- Several targeted research efforts to examine the current state of mathematics instruction in K–12 schools, with the intent of providing clearer direction for future research and development.

If sufficient resources are available, an early solicitation might also seek proposals for research-based development work in areas in which there is sufficiently promising theory to justify the investment.

The first of the two initiatives would signal the intent to support a solid and rigorous program of research in the three focus areas. The solicitation would seek proposals for work that builds on what is known, clearly specifies the research questions to be addressed, and uses methodologies appropriate to those questions. The results of the initial solicitation should provide important input to OERI and the proposed panels as they strive to build a cumulative and high-quality program of research and development.

The second component of the initial program effort would be somewhat more directed than the first. As we discussed in this report's introduction, mathematics education is a subject of considerable controversy. Claims and counter-claims abound concerning the value of various curricular strategies and curricula, requirements for teacher knowledge, and standards that students should meet. For the most part, these debates are poorly informed by solid research due to the dearth of such research. The program proposed in this report is most likely to gain the political support necessary for its success if it begins with activities designed to reshape these debates into empirically based investigations of the issues that underlie competing claims.

In this regard, we propose three classes of studies:

- Studies providing empirical input on the necessarily political decisions concerning standards of mathematical proficiency that students must meet
- Research intended to create a systematic picture of the nature of current mathematics education in the nation's classrooms
- Studies that assemble existing measures of mathematical performance or develop new ones that can be used throughout the proposed program.

The details of such studies should be developed by OERI and other funders working with research experts and educators from the field.

We illustrate the sorts of studies that might be done in the brief descriptions in the two text boxes that follow. The nature of these studies implies that further development of collective and collaborative efforts, such as those associated with The Third International Mathematics and Science Study (TIMSS), needs to be done. The studies exemplify some features of the collaboration among funders, researchers, and practitioners that we have recommended.

Research Related to Standards for Proficiency to Be Achieved by Students

One of the contentious areas in mathematics education is the standard that students should be expected to achieve and that the schools should be expected to enable students to achieve. Setting such standards is a political task rather than a research task. Nonetheless, empirical research on the needs of adults in the United States for proficiency in various areas of mathematics could help political bodies as they set such standards. Empirical research on the effects of current standards in specific communities could reveal the consequences of various formats and specifications of standards on the development of student proficiency. A matter of particular concern is the (often unanticipated) impacts that various specifications of standards have on diverse groups of students.

Research on the Nature of Current Mathematics Education in the Nation's Classrooms

While there is active and vigorous debate about the nature of the mathematics curricula that should be used in the nation's schools and the knowledge that is necessary for a teacher to be effective with those curricula, surprisingly little systematic knowledge exists about the actual implementation and use of programs and materials. Much of the evidence cited in these debates relies on anecdotes and firsthand experience. And the data used in these debates lack rigor, both in the nature of the information gathered and in the methods used

Example of Research on Existing Mathematics Curricular Materials

A possible starting point for examining the current practices in mathematics education would be to support systematic research on the quality and use of currently existing mathematics curricular materials. Some of these materials have been developed with support from the National Science Foundation, which expected that the developers would draw on the existing research base. Other materials are commercially developed and may or may not be research based. Some curricular materials are advanced by one side of the math wars and others by the other side. A coordinated program of research on mathematics curricula might, for example, have a middle school focus and ask:

- How do these materials deal with algebra?
- Who is using each of the various curricula, what is the extent of use, and what is the type of use?
- How distinct are these curricula in the algebraic content they cover?
- How well are the curricula implemented—are some easier than others to use appropriately by a broad range of teachers?
- What is the teacher knowledge implied by each curriculum, and how are middle school teachers distributed against that required knowledge base?
- What are the effects on gains in student achievement?
- How does the level of implementation, type of student, and knowledge of teachers explain these effects?

to analyze that information. For example, test score data are often used with little attention paid to the differences in student populations, the nature of the teaching staff, the levels of student mobility, or the character of the implementation of various programs.

One of the early initiatives in a program of mathematics education research and development should be a collaborative national effort to develop a systematic and empirical understanding of the actual nature of current mathematics education in U.S. schools. The goal of this part of the research and development effort would be to provide a grounded empirical base for policy concerning mathematics education and to provide a better understanding upon which to design improvement efforts.

Existing research efforts can provide some guidance and a base upon which to build further efforts. The TIMSS that compared mathematics performance internationally contains information on the nature of curriculum and instruction, and there is some limited information on curriculum and instruction in the

Example of Research on Existing Mathematical Knowledge of Teachers of Mathematics and Its Impact on Mathematics Instruction

Research has begun to uncover more about the role that mathematics knowledge plays in effective teaching. An initial program of research might build on this recent progress by focusing on the knowledge that teachers need to teach algebra at different levels. Questions include:

- What do teachers know of algebra and the skills and language related to the use and teaching of algebra? How does this compare across grade levels—elementary, middle, and high school?
- Are there recurrent mathematical issues that arise in the course of teaching algebra that demand specific teacher knowledge? In other words, are there some priority or high-leverage areas of knowledge for teaching algebra?
- In what ways does teachers' knowledge impact the quality of their teaching? What relations exist between particular types of teacher knowledge and their instructional patterns, and, in turn, their students' learning?
- What do different curricula demand of teachers?
- Are there types of curricula/programs (including technology) that can diminish the strength of the relationships between teacher content knowledge and student learning (i.e., support for teachers that enables them to be successful even when mathematical knowledge is lacking)?

A program of research on teacher content knowledge would require continued development of instruments to assess teacher knowledge. In the long run, we believe that measures of teacher content knowledge should be routinely included in all research studies of mathematics education.

National Assessment of Educational Progress. But much more needs to be done to create a national effort that engages excellent researchers and produces studies that build knowledge cumulatively. A significant design effort also would be required. Common measurement instruments would need to be designed or adopted and adapted. And, finally, a structure to manage the overall effort would need to be developed.

An effort such as this has several goals. The studies would establish a baseline against which changes and improvement (or lack of improvement) can be measured. They would describe the complex array of factors that determine the achieved mathematics proficiency of students. By going beyond single-factor explanations of effects, these studies would contribute to the development of more realistic designs for programs meant to improve the mathematical proficiency of all students.

Studies on the Development of Improved Measures of Mathematical Performance

The final activity that should be started early in the program is the development of measures and measurement instruments that can be used widely by those conducting the research on mathematics education. Without common and agreed-upon measures that permit comparisons of the study results of distinctive instructional programs or of similar programs in different settings, there will be an inadequate basis for building the rigorous program of research and development outlined in this report. Wide participation of the research community in the development of measures will be needed, and funders should be willing to specify where common measures must be used to promote the cumulative and scientific character of the program.

FUNDING RESOURCES

We made no attempt to estimate the cost of a program such as the one we propose. Obviously, meeting the program goals envisioned here will demand a significant investment of resources. The emphasis placed on enhancing the scientific rigor of the effort through the use of appropriate methods, replication of results, and wider use of experimental designs in tests of theories and hypotheses will require substantial support, and such work demands resources. Moreover, for new knowledge to find wide use in the classroom, it will need to be embodied in the curricula, materials, tools, and activities that themselves will require design, testing, redesign, retesting, and, ultimately, rigorous validation through solid research. This process, too, is expensive.

During the course of this study effort, we attempted to estimate the amount of resources that have been devoted to mathematics education research, excluding development. Including both NSF and OERI funding, the investment was estimated to be about $20 million annually between fiscal year (FY) 1996 and FY 2001. In FY 2002, NSF made significant commitments to a series of mathematics and science partnerships between universities and selected communities that will involve some research and development. Still, the funding is modest. By contrast, the early-reading research programs at NIH are currently funded at a level of more than $50 million annually in direct costs, also without much support going to development.

The program proposed here, particularly if it is to embody the work necessary to achieve high scientific rigor, clearly will require major increments in funding of mathematics education research.