THE MATHEMATICS EDUCATION PORTFOLIO BRIEF

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Since the National Council of Teachers of Mathematics (NCTM) initiated the standards movement in mathematics in the late 1980s, issues in mathematics education have become increasingly public and often controversial as academics, K–12 educators, parents, and business leaders have involved themselves in efforts to improve the mathematical proficiency of U.S. students. Because the National Science Foundation (NSF) has committed to improving education and, indeed, has invested heavily in mathematics education over several years, it is a good time to take stock of the nature and impacts of NSF's investments in mathematics education.

When Dr. Judith Ramaley, assistant director of NSF's Directorate for Education and Human Resources (EHR), began to explore this issue with the NSF staff and the field, it became clear that no easy answers would be forthcoming. Because EHR is organized into program areas by function (e.g., Instructional Materials Development, Research on Learning and Education) rather than by disciplinary focus, there are no convenient ways of summarizing NSF's investments in any particular focal or thematic area. To address this problem, Ramaley introduced the concept of conducting "portfolio reviews." These are efforts to answer questions about the nature, level and effectiveness of the NSF's investment in specific theme areas with mathematics education as the first. Portfolio reviews might also provide a basis for EHR's critical decisionmaking and resource allocation strategies.

In fall 2002, Ramaley initiated a comprehensive thematic and empirically based portfolio review to capture EHR's impact on mathematics education, spanning pre-kindergarten through grade 12, as well as the transition to college-level mathematics. The review concentrated on the period from 1994 to 2002, which fell within the timeframe covered by EHR's project abstract database. Relevant solicitations from 2003 were also reviewed.

Goals of Thematic Review

Thematic portfolio reviews are intended to inform future NSF/EHR decisions and investments. In addition, they are intended to establish a new form of accountability; to help clarify the appropriate role of NSF/EHR in improving science, technology, engineering, and mathematics (STEM) education; and to ensure legitimacy and appropriate diversity across the EHR investment portfolio. Specifically, the charge to the mathematics education review panel was to:

1. Design, describe, and implement an effective process for thematic portfolio reviews that

    - incorporates the advice of the expert panel of distinguished mathematicians and mathematics educators
    - includes an outreach component that incorporates feedback from the field
    - acknowledges and draws upon the collective expertise of program staff
    - leads to recommendations about how elements of portfolio review might be adapted into an ongoing monitoring system, or used in subsequent thematic reviews

2. Gather, analyze, and characterize baseline information about the mathematics portfolio in a way that

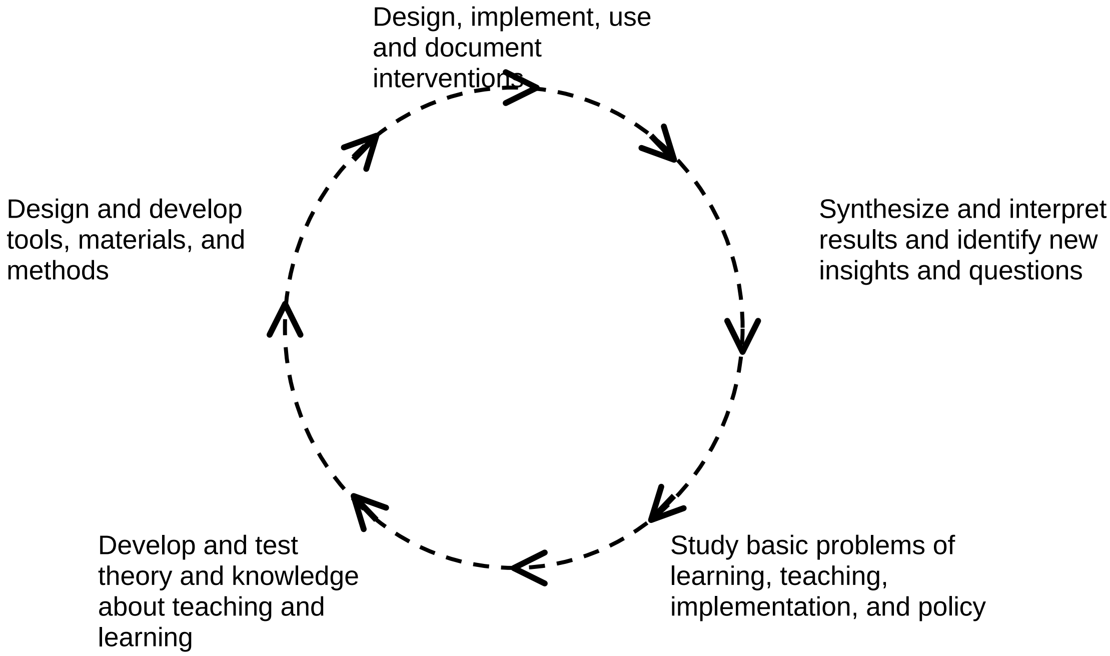
    - serves as a foundation on which to establish a cycle of discovery-innovation-application as a core approach to programming within EHR
    - serves as a basis for advice to EHR about future portfolio emphases and configurations, as well as programmatic strategies

3. Through the analyses provided by the expert panel, describe the relevance, quality, and performance of the EHR portfolio on the basis of existing evidence, to

    - determine how well the portfolio addresses the most significant challenges and opportunities in the field of mathematics education, pre-K–14
    - make recommendations for how the portfolio can and should relate to current and anticipated issues in the field
    - assess the nature of evidence about the portfolio and make recommendations about how to provide useful information on which evidence-based decisions can be made

The expert panel found it helpful to think about the different kinds of investments in the EHR mathematics education portfolio in terms of a cycle of discovery, innovation, and application (figure 1) adapted from the RAND Mathematics Study Panel. The cycle connects developing and testing theory and knowledge about teaching and learning; designing and developing tools, materials, and methods; designing, implementing, using, and documenting interventions; synthesizing and interpreting results and identifying new insights and questions; and studying problems of learning, teaching, implementation, and policy. A discussion of where the EHR mathematics education solicitations and projects fall along this cycle is included in the findings section of this report.

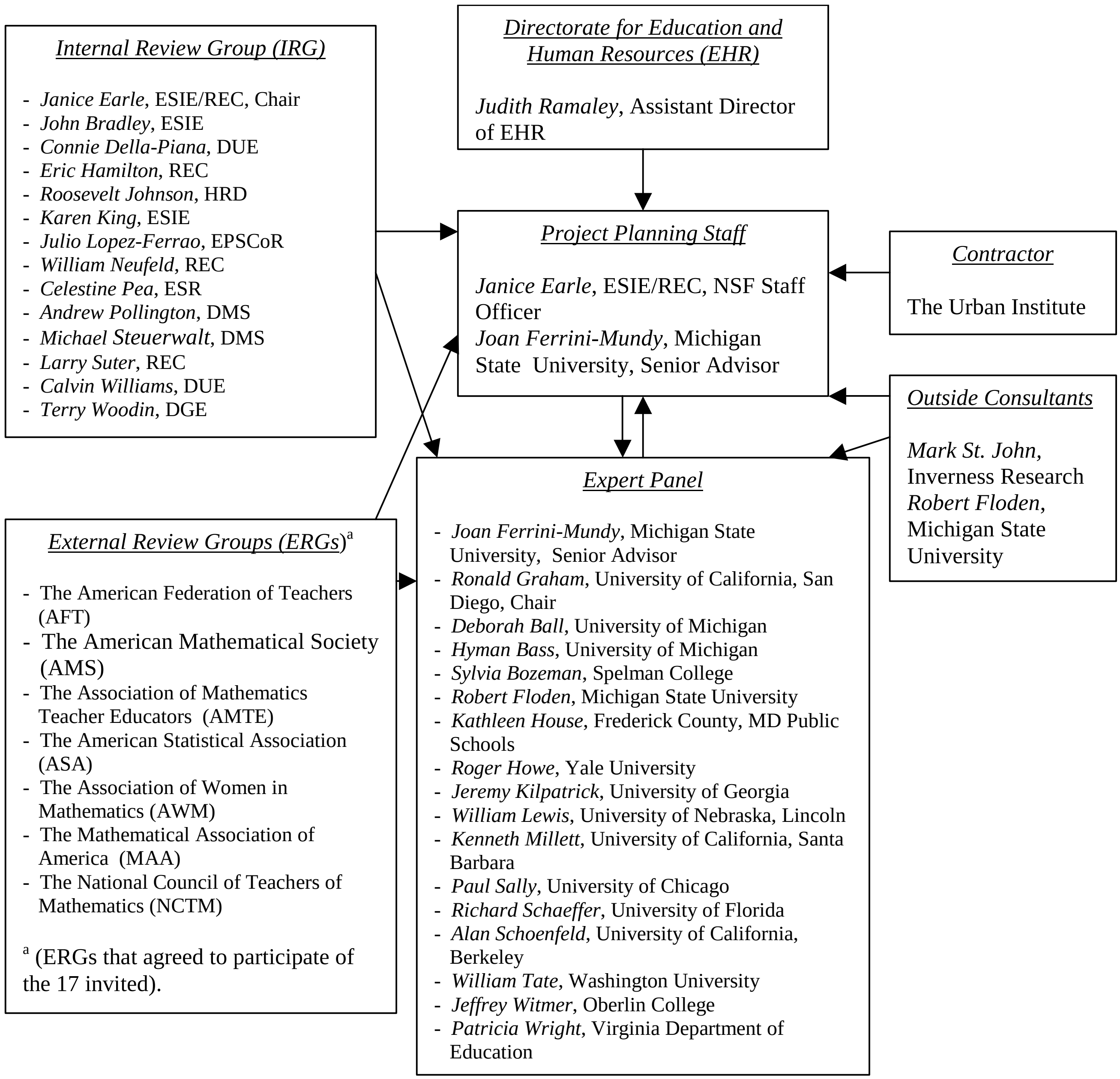
Figure 1. Cycle of Discovery, Innovation, and Application



Review Participants

The mathematics education portfolio review involved a panel of national experts in mathematics and mathematics education, external stakeholder groups who served as external review groups (ERGs), and internal NSF staff with detailed knowledge of NSF's work in mathematics education who served as an internal review group (IRG) (figure 2). The effort was directed by Janice Earle, senior program director in the Elementary, Secondary, and Informal Education (ESIE) and Research, Evaluation, and Communication (REC) Divisions of EHR, and by Joan Ferrini-Mundy, professor of teacher education and professor of mathematics at Michigan State University, who served as senior advisor. They were assisted by staff at the Urban Institute (UI) in gathering and analyzing material and preparing reports for the panel of experts.

Figure 2. Organization Chart: Mathematics Education Portfolio Review



Data Sources

The mathematics education portfolio review explicitly incorporated principles of scientific research; it was designed to base conclusions on empirical analysis. Analysis of clusters of related program solicitations and project jackets from the period of interest comprised the major part of this effort. The period 1994–2002 was identified because it was long enough to capture the full range of activities in the portfolio, but recent enough to give contemporary guidance. NSF also has relatively usable records on EHR's efforts during this period.

Program solicitations, including Dear Colleague letters that had some focus on mathematics education, were reviewed as one way of assessing the relevance, quality, and performance of EHR's mathematics education portfolio. All program solicitations issued from 1994 through 2002 that called for efforts in mathematics education were included in the review, as well as relevant solicitations from before 1994 and after 2002. A total of 133 unique program solicitations and Dear Colleague letters with some focus on mathematics education across EHR divisions and 35 EHR programs were collected. These solicitations were grouped into 13 thematic clusters and panelists reviewed all solicitations within a assigned clusters between the first and second panel meetings. Each cluster received at least two reviews.

A second major source of data was the project jackets. A project jacket is the official NSF-held record and documentation of a funded project. It covers all available information on a project, including the original proposal, reviews, and reports. For relevant projects to be reviewed, the universe of mathematics education projects had to first be defined and then a manageable sample within the universe selected. EHR's project abstract database was used to identify the EHR projects with some focus on mathematics. More specifically, projects were identified by conducting an analysis of keywords used in project abstracts. Abstracts were selected if they contained the following mathematics words or phrases: algebra, calculus, geometry, probability, proportion, ratio, statistics, pre-calculus, NCTM, estimation, mathematics teaching, mathematics tasks, mathematics framework, mathematics standards, mathematics curriculum, mathematics courses, mathematical thinking, discrete mathematics, mathematical understanding, mathematical problem solving, mathematical concept, mathematics assessment, and mathematical representation. EHR program officers and IRG members then checked and supplemented the generated list of projects. This process generated 1,277 total projects believed to be in the mathematics education portfolio, of the 8,338 projects in the EHR projects database from 1994 to 2002.

Project jackets cannot leave the NSF building because of their sensitive nature, so the number of panelists and the time allotted for reviewing projects during the panel's second workshop limited project reviews. A sample of 80 mathematics education projects was considered a reasonable number of projects for review. The central objective of the project sample was to select projects that were broadly representative of the mathematics education project portfolio for in-depth review, rather than to select a sample for statistical estimates. Four sampling scenarios were devised to look at projects by funding levels and focus. The plan selected was based on the distribution of mathematics education projects across funding levels and the distribution of mathematics education projects across clusters. The former ensured that the projects selected would include projects that represented NSF's largest investments and the latter ensured the inclusion of projects with different substantive foci. A list of projects in this sample as well as replacement projects was then generated and distributed to EHR staff, who were able to locate and collect the jackets. Some jackets were unavailable and some were simply not mathematics education projects. Ultimately, the panel reviewed 74 projects.

The planning staff next developed questionnaires for the panelists to use to review solicitations and project jackets. The goal of these questionnaires was to focus panelists' attention on particular information in the solicitations and project jackets and to help standardize reviews across reviewers and programs. Of particular interest was examining the mathematics education portfolio for its relevance, quality, and performance. Questionnaires described and then asked panelists to evaluate aspects of the solicitations and projects including the importance of the problem or goal; the theory of action or approach behind the solicitation or project; the actors, partnerships, or collaborations suggested or required; the quality of outcomes or products; any changes in focus over time (applicable to solicitations only); the level of innovation; and any other comment the panelist had. Data generated by panelists' responses to the questionnaires were used to describe solicitations and projects in the mathematics education portfolio and to suggest future directions for the portfolio.

In addition to reviewing the solicitations and projects, the expert panel conducted a "profile analysis" in four areas where related projects had demonstrated various effects over an extended period. Groups of projects identified for profile analysis included The Connected Mathematics Project, the Third International Mathematics and Science Surveys (TIMSS) and the Third International Mathematics and Science Surveys–Repeat (TIMSS R), The El Paso Urban Systemic Program, and Calculus Reform.

Another source of data was information provided by external mathematics and education stakeholder organizations that participated as ERGs. This background information was crucial for the panel to make informed judgments on EHR's mathematics education portfolio, particularly its relevance. ERGs were asked to share their views on what their organization saw as the greatest needs in mathematics education and what activities, if any, their organizations or other organizations were doing to address those needs. Outside consultants, including Robert Floden of Michigan State University and Mark St. John of Inverness Research, provided additional relevant background information, such as the relationships among the education governance systems (schools, districts, and state and federal governments) and the role and size of NSF's investment in that context, as well as some mathematics education topics, such as current state and national standards, curriculum/materials, and research findings.

Major Findings

The review characterized the mathematics education portfolio in two ways. First, the text of the solicitations and information available on the project abstract database helped characterize the portfolio with simple descriptors, such as the focus, activities, partnerships and amount of funding. Second, the expert panel characterized the portfolio in terms of quality, relevance, and performance after reviewing the solicitations and sample projects. As noted earlier, the review covered the period from 1994 through 2002 with some particularly relevant solicitations from 2003.

Portfolio Descriptors

The portfolio is described first through characteristics of the solicitations, then through characteristics of the projects. Solicitations are discussed in terms of their activities and specified partnerships. The projects provide a more detailed picture of EHR's investment in mathematics education.

- *Solicitation Activities*. The solicitations in the portfolio had the common goal of improving STEM education, but the focus and called-for activities varied widely. The solicitations included systemic reform efforts, shaping of teacher preparation and professional development models, developing new materials for teachers and students, research on teaching and learning, promoting increased informal education and parental involvement, technology education research and programs, improving various aspects of early undergraduate education, and new approaches to STEM education for specific populations.

- *Solicitation Partnerships*. The solicitations commonly encouraged and sometimes required partnerships among various education stakeholders: local schools, universities, community organizations, local businesses, and, in the cases of systemic reform, local school districts or state education agencies.

- *Project Funding.* EHR's investment in mathematics education was examined at the project level because dollar amounts were only available in the project database. Observations on funding patterns follow.

    1. *Share of EHR project money*. Among all EHR projects from 1994 to 2002, approximately 15 percent (1,277 projects) were identified, through an abstract database or by EHR staff, as having at least some focus on mathematics education. The amount spent on these projects constituted $1.8 billion (approximately 36 percent) of the $5 billion spent on all EHR projects for the period.

    2. *Size of mathematics-related education projects.* Mathematics-related education projects tended to be large. Indeed, over 90 percent of funding for projects related to mathematics education are funded near or above $1 million. These numbers, however, should be considered an upper bound of spending on mathematics education because many projects, especially the larger ones, focused on other subjects, such as science, as well as mathematics.

    3. *Shifts over time*. Over the period studied, there were a few noticeable shifts in features of the projects in the mathematics education universe. Specifically, large project funding increased and greater emphasis was placed on research and evaluation.

Panelists' Portfolio Characterization

Panelists reviewed the universe of program solicitations and a sample of project jackets to judge the relevance, quality, and performance of the mathematics education portfolio. Rating the relevance of the portfolio was easier than rating the quality or performance of the portfolio because of limited information in project jackets. Despite informational limitations, panel discussions resulted in eight central themes or "considerations" on which the panelists shared their views of the relevance, quality, and performance of NSF's mathematics education portfolio. Considerations are enumerated below with a brief summary of panelists' views on each one:

> *Consideration 1. How well does the mathematics education portfolio map to the cycle of discovery, innovation, and application?*
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>> Information from the panel's solicitation and project jacket reviews suggests that a majority of the portfolio is located in the "design, implement, use, and document interventions" and "design and develop tools, materials, and methods" parts of the cycle as opposed to the "research on the basic problems about teaching and learning," "develop and test theory and knowledge," and "synthesize and interpret results and identify new questions" parts (see figure 1). Design and implementation projects were criticized by some panelists as lacking a research foundation and failing to add to the knowledge base. At the same time, there was some critique of research projects that seemed unlikely to contribute to practice.
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> *Consideration 2. How is the integrity of mathematics content addressed in the mathematics education portfolio? Do solicitations and projects attend appropriately to issues related to mathematics in teaching and learning contexts?*
>
>> Panelists emphasized the importance of the integrity of mathematics in the projects and solicitations. All panelists support the notion of mathematics that is correct and appropriate, recognizing that determining what mathematics is appropriate requires a blend of expertise about mathematics, teachers, children, and schools, and thus will necessitate the involvement of mathematicians together with other professionals with appropriate expertise.
>
> *Consideration 3. Does the portfolio reflect an intentional, sustained focus on key lines of work? Are awards of sufficient size, scope, and duration to ensure long-term impact?*

Panelists noted that projects attempting new approaches and even those using standard approaches (e.g., teacher professional development, teacher preparation) may not be sustainable once the NSF funding is complete. The panel felt that many projects need more time than the funding period to accomplish their work, and that lasting impact would be difficult to see until long after funding ended. At the same time, some panelists expressed concerns about the large proportion of mathematics education funding that was committed to large-scale longer term projects, such as partnerships with state and local education agencies.

Consideration 4. How solidly does the portfolio rest on a base of research and theory, and on systematically accumulated wisdom from practice? Do the products of the portfolio contribute to research and theory, and to the base of practical knowledge for improving mathematics teaching and learning?

Several panelists held a strong view that the impact and effectiveness of the portfolio would be enhanced with more deliberate efforts to build on existing knowledge bases (including knowledge from practice) and theoretical perspectives.

Consideration 5. How well are issues of evaluation addressed in the portfolio? Is relevant ongoing expert input part of the solicitation and project design?

Panelists emphasized the value of requiring rigorous evaluations of the projects. Judging from the panelists' inability to find much about evaluation in the project jackets, it seems that new processes could be designed for gathering and using both ongoing and final evaluation reports. Panelists urged that significant products of various projects undergo more systematic outside review.

Consideration 6. What is the range of expertise involved in the EHR mathematics education projects, and is that expertise well aligned with the work? Are appropriate multidisciplinary perspectives encouraged?

Panelists found that most solicitations were explicit about the kind of expertise needed and generally agreed that the solicitations called for the appropriate expertise mix. In the case of implementation and intervention programs, panelists also agreed with the need to involve parents, the community, school systems, and professional organizations, along with higher education, to effect the kinds of complex and sweeping changes expected. Some panelists suggested that representatives of the media, brain researchers, and scientists might be helpful in certain solicitations.

Perhaps the most salient expertise issue centered around the roles and contributions of mathematicians and mathematics educators. Generally, panelists agreed that expertise appropriate for solving the central problem or for addressing the goals of a project should be assembled to undertake the project, and did not feel that "balance" was a useful metaphor in discussing the involvement of mathematicians, mathematics educators, and school personnel. They also felt that solicitations could suggest collaborations between mathematics educators and mathematicians, thereby promoting a productive blending of expertise.

Consideration 7. How do the NSF infrastructure, processes, and procedures support the strategic development of solicitations that can benefit mathematics teaching and learning?

Throughout the review process, panelists had a number of questions about how solicitations are designed, whether they are constructed to be responsive to, or proactive and prescriptive about, issues of the context of and needs in the field. The review revealed some solicitations that were developed in response to the needs of the field. Interviews with NSF staff concerning calculus reform and knowledge on NCTM's *Curriculum and Evaluation Standards* and EHR's Research on Teaching and Learning Program suggested that EHR has built programs in response to concerns in the field. Panelists suggested these situations as examples of how NSF/EHR appeared engaged in a strategic, responsive approach. They also were interested in whether connections are systematically built across solicitations. Panelists saw examples where there was potential for greater connection among projects.

Consideration 8. Are external contexts, needs, and issues in the field taken into account as programs are designed and implemented? Do solicitations allow for innovation, and can the portfolio be characterized as innovative?

Panel discussions also acknowledged that in order to design solicitations to be both responsive to and proactive about the needs of the field, NSF staff needs ongoing opportunities to exchange ideas with practitioners across the mathematics education spectrum. As far as the level of prescriptiveness in solicitations, the panel felt that solicitations should be realistic in setting expectations to ensure certain fundamental elements, while leaving space for innovative and creative approaches. Panelists felt strongly that solicitations should not dictate particular philosophical approaches to mathematics education. Overall, the panelists found the projects' approaches appropriate.

In the panelists' view, the portfolio would not be characterized as highly innovative in terms of either the ideas proposed or the implementation and design of the projects. Panelists did not see this as a problem; their view was that the EHR mathematics education portfolio should aim to improve mathematics education, and that innovation was not necessarily the route to improvement.

Implications

The work of the panel and of EHR staff throughout the mathematics education portfolio review has yielded several important outcomes and opportunities for EHR to improve its impact in the field. Panelists introduced the following three “nonnegotiable” aspects of the portfolio as it is built in the future:

1. Ensuring mathematical integrity and quality through involvement of mathematicians and mathematics educators, while remaining neutral toward various mathematics curricula.

2. Building programs and projects on foundations that draw upon education research and theory.

3. Funding programs and projects that generate knowledge to contribute to the field.

Some additional opportunities for EHR’s mathematics education portfolio that resulted from the review are outlined below:

1. Using of the portfolio metaphor as a tool not only to study NSF’s contributions to subject fields such as mathematics, but also to think about NSF’s investments across EHR divisions, programs, and projects.

2. Changing the culture of EHR by increasing interaction with outside expertise from the field and building capacity within EHR to conduct more scholarly work that is more coherent across divisions.

3. Improving solicitations and projects along several portfolio dimensions such as connection to all parts of the cycle of innovation (from research to capacity building to direct service), balancing the number of large and small projects, connectivity among projects, involvement of appropriate expertise, and accurate and thorough project reporting.

4. Collecting additional information on programs and projects and improving existing databases to better track information on programs and projects within the portfolio.

Conclusion

The collaborative engagement of NSF staff and outside experts in a systematic review of NSF's mathematics education portfolio stands to influence a broader vision and understanding of issues in mathematics teaching and learning and of the direction and value of NSF's efforts. With the development of such understanding, EHR will be in a stronger position to assess how various projects and programs truly build our knowledge base.

The mathematics education portfolio review has been worthwhile and productive. In the long term, its ramifications may ultimately be visible in changed processes, structures, program design, and portfolio management at the NSF, and in more substantial capacity across the nation to bring research-based knowledge and experiential wisdom to the improvement of mathematics teaching and learning.