Although a goal of this book is to discuss some of the most important criteria for assessing and optimizing the quality of research designs that appear to be especially promising for research on mathematics and science education, we make no attempt to establish an agenda for such research. In particular, this book is not about what kind of problems should be the most important to address, nor is it about what kind of theoretical perspectives should be favored. Yet, when panels of reviewers assess the quality of research proposals or publications, they consider more than the quality of the research design. For example, in mathematics and science education, high-quality research projects generally are intended to make a difference to both theory and practice. They tackle important problems or issues, and they lead to extensions, modifications, or revisions of a significant base of knowledge. Therefore, to assess proposals or publications for a particular organization or agency, reviewers take into account answers to the following types of questions:

- What kinds of decision makers and decision making issues does the organization or agency believe should be given priority? For example, should the policy-level decisions of administrators and politicians be given priority over the classroom decision-making issues that confront
teachers and students? Should projects be supported in which mathematics or science could be replaced by such terms as literature or social studies or art? That is, should investigations be supported that deal with general education issues, or general management issues, or general policy issues, or general issues involving the dissemination of knowledge and the implementation of new scholarship in which the quality of the subject matter is not considered?

- What levels and types of subjects does the organization or agency want to generate more knowledge about? For example, should new information or new ways of thinking about the development of students and teachers be given priority over information about the development of schools or school systems, or the development, dissemination, and implementation of programs or curricular materials? What balance should an organization attempt to achieve among these factors?

- What "grain size" (level of detail) does the organization or agency consider to be most productive for describing the preceding subjects? What dimensions does it believe should be emphasized? For example, is information about the general behavior of groups viewed as being more significant than information about the detailed behaviors of individuals? Does a social perspective appear to be more useful than a cognitive perspective? Does a developmental perspective seem more likely to be useful than "status studies" at isolated intervals?

- What problems or issues does the organization or agency consider to be the most important to address about the preceding subjects? For example, should attention be focused on issues involving equity, content quality, standards, assessment, or school-to-work transitions? Should problems be emphasized that focus on policy issues or school-level decision making, even if these issues have little to do with the quality of mathematics and science instruction? To what extent should research be proactive (by attempting to investigate tomorrow's issues, perhaps related to innovative uses of technologies) rather than reactive
3. RESEARCH AGENDAS

(by restricting attention to solutions to problems that are priorities today)? Should the problems of inner-city minority students be given priority over those of other populations of students? Should the problems of nonindustrial societies be favored over those associated with technology-based, job opportunities?

- What kinds of conceptual frameworks or theoretical perspectives does the organization or agency consider to be most useful? For example, does the agency consider studies based on constructivist philosophies to be more promising and, therefore, more worthy of support than studies based on other perspectives?

- In what form does the organization or agency believe that relevant information should be delivered in order to be useful? For example, should the deliverables emphasize the development of knowledge (e.g., shareable and reusable information that is relevant to the priority, decision-making issues in mathematics or science education), the development of materials (e.g., textbooks, software, or videotapes), the development of programs (e.g., workshops or sequences of experiences that can be replicated and disseminated), or the development of teachers (e.g., enabling them to become certified as having achieved certain specified goals)?

Generating answers to the preceding types of questions is one of the most important challenges faced in formulating a research agenda for a particular organization or agency. But, in general, this book is not intended to address such questions. For our purposes, answers to such questions become relevant only if they have bearing on principles that researchers should consider in order to conduct (for example) high-quality clinical interviews, teaching experiments, or videotape analyses. Therefore, instead of attempting to provide answers about priority problems and perspectives, the authors in this book were asked to assume that most of these agenda-setting issues will be resolved by the funding agencies or professional organizations that will review proposals or publications. Our goal is to address a much more restricted set of issues that arise after decisions have been made about which problems and perspectives should be treated as priorities. That is, we focus on the internal logic of the processes of gathering, analyzing, and interpreting information, namely:
perspectives should be treated as priorities. That is, we focus on the internal logic of the processes of gathering, analyzing, and interpreting information, namely:

- Are the processes of data collection, analysis, and interpretation consistent with relevant assumptions about the nature of the subjects being investigated? For example, in research on teaching and learning, the subjects being investigated may range from students, to groups, to ideas, to software, to teachers, to schools, to programs, and to other kinds of complex systems that tend to react and modify themselves as a result of being observed. Therefore, in such instances, it often is inappropriate for researchers to rely on data collection methods that presuppose measurements that are completely unobtrusive.

- Are the processes for analyzing data consistent with assumptions about relevant characteristics and behaviors of the systems being investigated? For example, when complex, adapting, self-regulating systems are investigated, relevant characteristics and patterns of behavior often interact in complex ways that involve recursion and chaos. Consequently, in such instances, it may be inappropriate for researchers to rely on data analysis techniques that are based on simple linear models in which relevant characteristics and behaviors are treated as if they were independent or dependent variables within simple cause-and-effect interactions.

- Are the criteria for assessing the usefulness of constructs consistent with assumptions about the nature of relevant decision making issues and the relevant decision makers that these constructs are intended to inform? For example, in the assessment of students' achievement, information and ways of thinking that are useful for critical decision making by college admissions officers may be relatively insignificant in the context of less momentous iterative decision making by classroom teachers. Therefore, to design relevant research, decisions must be made that involve trade-offs among factors such as accuracy, precision, timeliness, and consistency. This is because research design
strategies that have a positive effect on one of these factors often have negative effects on others.

**WHAT FACTORS INFLUENCED OUR CHOICE OF THE RESEARCH PROCEDURES EMPHASIZED?**

Although the editors of this book considered it neither feasible nor desirable to restrict attention to any single theoretical perspective or any one set of problems, the research procedures that we chose to emphasize include clinical interviews, teaching experiments, videotape analyses, ethnographic observations, and other qualitative methods that often incorporate action research in which the roles of practitioners and researchers become blurred. Not only are these research procedures that have taken on distinctive characteristics when they have been used in mathematics and science education, but they also are research procedures that have been used extensively around the world for addressing many types of problems from many different perspectives. Yet, most of these perspectives emphasize constructivist ways of viewing students, teachers, classrooms, schools, and school districts: also, most of the research procedures that we emphasize were designed specifically to decrease the gap between researchers and practitioners, perhaps by including teachers and other practitioners in the research process or perhaps by stressing field-based, rather than laboratory-based, investigations.

In general, we have emphasized qualitative research procedures more than quantitative procedures mainly because a wealth of resources exists already in which quantitative methodologies are highlighted. Further, we have underlined psychological issues more than other perspectives because, during the past few decades, some of the most productive branches of mathematics and science education research have focused their investigations on how the ways of thinking of students, teachers, or others who are involved in mathematics and science education develop. Therefore, these are the areas where the development of new research designs has flourished.

Beyond the aforementioned prejudices, our discussions about research designs take place in the context of specific problems and perspectives. Consequently, to help coordinate the discussions in various chapters of the book, it was useful to choose a few themes (problems
and perspectives) that might help to ground the discussions in specifics. Yet, at the same
time, these themes needed to be chosen in such a way that they did not narrow the relevance of
the book needlessly to include only those who share these prejudices. The research agenda that
we chose in order to provide unifying themes is the one that was adopted by the organization
that funded most of our efforts: the United States’ National Science Foundation Program for
Research on Teaching and Learning (RTL).

The research agenda for the RTL Program is given in the Appendix to this chapter. It was
ideal for our purposes because it was formulated explicitly to enable most mathematics and
science education researchers to fit within its framework. Yet, the themes that it emphasized
enabled the program as a whole to describe the results of funded research projects in a form
that is meaningful to politicians, bureaucrats, business leaders, and others who must support
such efforts ultimately. Also, the subjects to be investigated can range from students, to
teachers, to classrooms, to schools, and to programs; and, the general issues that it addresses
can range from equity, to content quality, to preparation for success beyond school, and to
technology in education. Therefore, the framework imposed few constraints on our discussions
of research designs; nevertheless, it helped the authors to coordinate their efforts.

WHY DO PROFESSIONAL ORGANIZATIONS AND FUNDING
AGENCIES CHANGE THEIR RESEARCH PRIORITIES
FREQUENTLY?

Another reason to avoid restricting attention to a narrow research agenda is that a variety of
reasonable responses can be given to the kinds of agenda-setting questions that are described in
the previous section. There is no single set of “right answers.” Also, no professional
organization or funding agency has more than a small amount of resources that it can use to
help improve educational practice. Therefore, each tends to focus on a niche that will provide
maximum leverage in the problem areas that it considers to be the most strategic for achieving
the sorts of significant impacts that it seeks. As a result, different organizations and agencies
tend to answer the preceding questions in different ways, and, in order to respond to the
changing realities of both theory and practice, they review and revise continually their official
opinions about priority problems and strategic directions for research and practice.
IN WHAT WAYS DO CHANGES IN RESEARCH AGENDAS IMPACT CHOICES OF RESEARCH DESIGNS?

When a research agenda is specified, there are various ways that choices about problems and theoretical perspectives influence the kinds of research designs that are emphasized. Possibilities may range from proof-of-concept studies (such as those involving the use of innovative software or curricular materials), to case studies (such as those concerned with the dissemination or implementation of complex programs, or professional development), to surveys (such as those aimed at information for policy makers), to action research studies or teaching experiments (such as those featuring the classroom practices of effective teachers), to ethnographic observations (such as those whose purposes are to identify the kinds of mathematical or scientific understandings that are needed for success in various contemporary professions), and to detailed clinical interviews or videotape analyses (such as those seeking to clarify the categories of mathematical understandings and abilities that contribute to success in targeted types of real-life, problem solving situations).

To decide which of the preceding kinds of investigations may be most appropriate, another important factor to consider is the maturity of the relevant theoretical models. Sometimes, what is needed most is model construction, or model elaboration, or model extension; but, at other times, model testing and verification, or model revision and refinement are called for. Sometimes, hypothesis-testing studies are required; at other times, exploratory hypothesis-generating studies aimed at finding productive ways to think about the relevant situation are needed in order to advance the state of knowledge. Sometimes, premature attempts at quantification may be foolish, but, at later stages of development, the lack of measurable and clearly defined constructs may hinder progress.

Whereas the products that some studies yield may consist of rules or generalizations for which it is appropriate to ask whether the construct is true or false, other types of investigations may lead to products consisting of descriptions or explanations of complex systems, so that the kinds of criteria that are appropriate for judging quality are similar to those that apply to portraits of people, or to blueprints for houses. One does not ask whether portraits or blueprints are true or false; instead, we ask whether they are meaningful and useful, revealing and illuminating, internally consistent, sufficiently detailed, fuzzy and flawed. Therefore, among the research designs described in this book, many of the most
important issues that we need to address are those that are related to criteria for judging and optimizing the quality of the results that are produced by the various kinds of investigations.

NEW WAYS OF THINKING ABOUT COMMUNICATION BETWEEN RESEARCHERS AND PRACTITIONERS

Another factor that influenced strongly the research procedures stressed in this book was the sensed need to increase the timeliness and usefulness of the results that are produced by mathematics and science education researchers. On the one hand, from the perspective of practitioners who are critical of the mathematics and science education research communities, a perceived shortcoming is that researchers often seem to be driven by their whims and curiosities rather than by an attempt to investigate real problems. Therefore, the advances in knowledge that such researchers make often seem to practitioners to be irrelevant to the decision-making issues that they consider to be priorities. On the other hand, some of these dissatisfactions are the result of inappropriate traditional ways of thinking about productive links between theory and practice.

To develop more productive links between theory and practice, it is naive to think in terms of a one-way process in which practitioners present problems and researchers provide answers that are distributed through external agents. Traditionally, in education, ideas about information dissemination have been based on models and metaphors borrowed from agriculture, where new ideas were distributed in much the same way as fertilizer. But, today, in mathematics and science education, this way of thinking has proved to be inadequate. For example:

- It is misleading to imagine that mathematics and science educators can be sorted into nonoverlapping categories such as "researchers" and "practitioners." There are many other types of people besides teachers and researchers who are involved in the mathematics and science education enterprise. For example, other significant participants include curricula developers, teacher-educators, and school district curricula supervisors. Furthermore, many leading researchers are among the nation's most influential teachers, teacher-educators, curricula developers, or curricula reformers. Similarly, many outstanding
practitioners are deeply involved in projects whose main goals are to generate new ways of thinking about the development of students or teachers or new ways of thinking about program development, implementation, and dissemination. Therefore, the kinds of research designs that are emphasized in this book include teaching experiments, action research, and other approaches to the development of knowledge in which the distinctions between researchers and practitioners are blurred.

- In mathematics and science education, the flow of information between researchers and practitioners is not the kind of one-way process that is suggested by such terms as information dissemination. Instead, to be effective, the flow of information usually must be cyclic, iterative, and interactive. One reason this is true is because researchers are not necessarily skilled at communicating their results in forms that are useful to teachers, and teachers are not necessarily skilled at describing their problems in forms that are researchable. As folk wisdom suggests, a fish is not necessarily the animal most likely to discover water. Quick fixes often focus on symptoms rather than causes; thus, a clear recognition of a pain is not the same thing as a clear conception of a solvable problem. Furthermore, research is similar to other forms of learning in the sense that an important goal of research is to look beyond the immediate and the obvious and to focus on what could be in addition to what is. Consequently, some of the most important contributions that researchers make to practice often involve finding new ways to think about problems and potential solutions, rather than merely providing answers to specific questions. Similarly, some of the most important contributions that practitioners make to research cannot be delayed until the final stages of projects when results are translated into a form that is intended to be meaningful and useful. Therefore, the kinds of research designs that are stressed herein often involve teachers, as well as other types of practitioners, at early stages of the projects,
and the knowledge that is developed often is embedded in curricular materials, educational programs, or models for teaching and learning.

- Traditional views of program implementation tend to be based on machine metaphors in which schools are treated as if they are factories that can be broken into components and assembled one piece at a time. But "delivery-and-reception" models have proved to be far too simplistic to describe the development of complex systems, regardless of whether the "individuals" involved are students, teachers, groups, classrooms, schools, or school systems. As the chapter of this book on operational definitions (Lesh & Clarke, chap. 6, this volume) explains, all of these individuals involve systems that are more like complex and continually adapting biological systems than they are like simple machines. In each case, the system as a whole is more than the sum of its parts; the parts interact in complex and recursive ways, and, when actions are applied to these systems, the systems react. Therefore, when the goal is for a particular system to evolve in desirable directions, it is not enough for "good ideas" to be delivered and "bolted down" like isolated components in a machine. Instead, new ways of thinking need to be developed through extensions of, and adaptations to existing sound systems. As a result, the research designs that are highlighted in this volume frequently go beyond investigating isolated individuals and focus also on interactions among and between the development of students, teachers, curricular materials, and programs of instruction.

- Because of the complexity of the problems and the systems that need to be understood in mathematics and science education, single, isolated, research studies seldom produce results that are useful immediately for solving real-life problems. In most of the cases that occur in mathematics and science education, both the problems and the solutions are far too complex to lend themselves to simplistic, one-study-to-one-solution approaches to progress. Instead, a series of investigations conducted over a considerable tends to be needed. For real progress to be
made, knowledge must accumulate. Therefore, rather than judging the usefulness of research projects based on the notion of a one-to-one correspondence between problems and projects or solutions, a more productive approach is to expect each study to contribute to the development of a community of knowledge, materials, and programs that should be expected to produce significant results over a reasonable period of time. In research, as in curricula reform, piecemeal approaches to progress are seldom effective to induce changes in knowledge and abilities, systemic and systematic research programs are needed.

FOR PROGRESS TO BE MADE, KNOWLEDGE MUST ACCUMULATE

Another force on many of the research procedures described in this book was the desire to find appropriate balances and interdependencies among projects that focus on the development of knowledge versus those that focus on the development of curricular materials, students, teachers, groups, classrooms, programs, or other relevant complex systems.

To achieve appropriate balances among these kinds of projects, one question that we considered was: How much progress have mathematics and science education projects made since the time of the “new math” projects of the 1960s? Our conclusion was that, regardless of whether the projects being considered focused on materials development, students’ development, teachers’ development, or program development, the following generalizations tended to be true: In projects where progress has been made, it is because more is known at the end of the project; in projects where little significant progress has been apparent, it is because these projects have failed to build on one another’s work in systematic ways. Consider the following examples:

- *Projects that focus on the development of curricular materials.* Have curriculum development projects built on their successes and failures in systematic ways? Have assessments of projects gone beyond simplistic claims that “It works!” to address such questions as: who, what, when, where, and why? With whom does it work and in what ways? What
components work best for which purposes, and what components are missing or relatively ineffective? When and where does it work and under what conditions? Why do the preceding components work and how could improvements be made? In cases where these kinds of questions have been addressed in nonsimplistic ways, and in cases where the results were expressed in a form that was meaningful and useful to others, such materials development projects have contributed not only to the development of new curricular materials but also to what is known about teaching and learning. Unfortunately, relatively few curriculum development projects have treated "knowing more" as a major goal of their efforts. Consequently, progress has tended to be serendipitous.

- Projects that focus on the development of teachers. Are preservice or inservice projects for the development of teachers today improvements over their counterparts from 30 years ago? In cases where the answer is "yes," projects have tended to be based on research that focused on the development of students' knowledge, teachers' knowledge, and classroom practices. Examples of such projects include many whose directors are authors represented in this book or other well-known researchers (Ball, 1991; T. Carpenter & Fennema, 1992; T. Carpenter, Fennema, & Lamon, 1988; Cobb & Bauersfeld, 1995; Confrey, 1986, 1990; R. B. Davis, Maher, & Noddings, 1990; Hestenes, 1994; Lampert, 1985, 1988; Post, Behr, Lesh, & Harel, 1988; M. Simon & Schifter, 1991; A. Thompson, 1984, 1989; Warren, Rosebery, & Conant, 1994). Conversely, in the area of teachers' education where little progress has been made, the same mistakes tend to occur repeatedly in one project after another. For example, the results of development projects for teachers often are assessed using such naive indexes as minimizing dollars-per-contact-hour or maximizing the number of teachers "touched." Yet, it is well known that brief and superficial experiences are seldom effective in promoting sustainable
changes in classroom practices. Similarly, models for teachers inservice education continue to rely on brief summer workshops followed by a small number of brief, school-based observations, demonstrations, or discussion. Further, models for disseminating (or scaling up) these programs tend to rely on a cascading, “chain-letter” mechanism in which mentors pass on good practices to colleagues who, in turn, pass them on to others. However, it is well known that far more sophisticated forms of support are needed in order for the half-life of an intended change in practice to survive more than a single link in this cascading chain.

- Projects that focus on the development, dissemination, and implementation of innovative programs of instruction. Again, are today’s projects an improvement over their counterparts from 30 years ago? The answer to this question is more definitely “no” than the answers to the questions about changes in projects for the development of curricular materials and teachers. Although simpleminded, “delivery-and-reception” metaphors are recognized widely now as being inappropriate for describing the development of students, teachers, or other complex systems, these same machine-based metaphors continue to be applied to the development of programs of instruction. The goals of such programs continue to be reduced to naive checklists. Tests that are aligned poorly with the goals of instruction continue to be used. Accountability practices typically have largely negative influences on what is taught and how it is taught and activities that are means to other ends tend to be treated as if they were ends in themselves. For example, teachers’ workshops tend to be held, or new computer laboratories are created, as if they were ends in themselves apart from any goals related to students’ achievement. In an attempt to avoid having curricula reforms appear to be top-down impositions, blue ribbon panels of teachers often rewrite local versions of national standards for curricula and instruction, and/or they attempt to write new materials for assessment or instruction. Yet, asking a small committee
of expert teachers to create local standards seldom makes these standards any more local than those that were defined by national committees. Furthermore, curricular goals that are defined only by "school people" usually do not enlist support from knowledgeable parents or leaders in the community. Also, because teachers usually are given insufficient time to perform the preceding tasks, which they often are expected to carry out in addition to their other duties, the materials they produce seldom pass through the kind of quality assurance procedures that are needed in order to ensure that adequate attention has been given to such issues as equity, reliability, or validity. Furthermore, teachers who are involved in such efforts usually must take time away from precisely what they do best, which is interacting with students.

Among the difficulties mentioned in the preceding examples, nearly all of them resulted in pressing needs to develop new information and new ways of thinking about teaching, learning, and problem solving or the development, dissemination, and implementation of instructional programs and materials. Yet, many people involved in the reform of curricula claim that: "We know enough! All we need to do is to do it!"

We agree that curricula reform does not need to be delayed until many years and millions of dollars have been spent on more research. But, at organizations such as the United States' National Science Foundation (NSF), there never has been a danger that this possibility would occur. For example, traditionally, the NSF has spent orders of magnitude less money on educational projects that were aimed at the development of knowledge than those that focused on the development of curricular materials, instructional programs, teachers, and school systems. In fact, in recent years, the NSF has dedicated less than 1.6% of its education budget to projects whose main deliverables involved basic research on teaching and learning. Furthermore, whereas RTL-funded projects typically involved significant components related to the development of instructional materials, programs, or teachers, it has been rare for projects funded in these areas to involve significant components aimed at knowing more about problem solving, teaching, and learning.

The preceding observations are important because they suggested to the editors of this book that if research in mathematics and science education is going to get enough support to
be effective, the kinds of research designs that need to be emphasized are those that: (a) can be conducted within the context of other types of projects, (b) are likely to lead to results for projects whose main goals stress the development of materials, software, teachers, programs, or effective school systems, and (c) go beyond studies aimed at yielding information about the development of individual students and teachers to focus also on information about the development of classrooms, schools, curricular materials, and other kinds of complex systems that need to be understood better in order to make significant and sustainable improvements in mathematics and science education.

The examples described throughout this section suggest that there should be an enormous return from giving greater attention to the development of knowledge projects whose objectives are the development of materials, programs, and teachers. For example, new math projects of the 1960s experienced many difficulties because little was known about the nature of students' ways of thinking about the fundamental principles of mathematics and science. But, today, a great deal has been learned about how students and teachers develop their mathematical and scientific knowledge. This fundamental research on teaching and learning has been one of the main factors leading to the successful development of standards to assess the achievements of mathematics and science instruction. Conversely, in areas where the research base on teaching and learning is least solid and extensive, standards-based efforts to improve curricular have been proportionally weak. For instance, the development of standards for curricula and evaluation has been far more effective in mathematics than in the sciences; it has been far more effective for elementary school and middle school courses than for high school or college courses; it has been far more effective for the education of students than for the education of teachers; and it has been far more effective in physics than in most of the other sciences. Moreover, the impact of standards-based curricula reform has tended to be directly proportional to how much is known about students' relevant ways of thinking and about how to mold and shape students' knowledge through the use of appropriate, small-group interactions, manipulatable materials, and other devices designed to increase representational fluency.

For certain topic areas in mathematics and science, a great deal is known about how students develop their ways of thinking about important constructs. But what does it mean for teachers to have deeper or higher order understandings? Do teachers need to develop understandings beyond those that are appropriate for their students? Surely, most people would
agree that, for complex topics such as linear equations, teachers need to know more than their students. But how much more do they need to know? Also, do they need to know what they know differently? For example, beyond knowing what their students should know, teachers probably should know something about how relevant ideas develop: (a) psychologically (in the minds of students), (b) historically (among earlier generations of mathematicians), and (c) instructionally (in high-quality, curricular materials). They also should know something about the ways in which these ideas are used in real-life, problem solving situations. But what other understandings and abilities are required? Clearly, more research is needed.

SUMMARY

This chapter describes some of the most important criteria that were used to choose the research designs featured in this book. It is important to consider these criteria not only because they influence strongly the choices that researchers make when they design specific research projects, but also because they influence the extent to which the results of research produces are likely to be viewed as useful by practitioners.

As noted earlier, one reason for giving special attention to the research agenda for the NSF's RTL Program is because it helped to coordinate the discussions in various chapters of this book. Another reason for considering this program is because even though other countries, organizations, and agencies emphasize different problems, perspectives, and approaches, the kinds of issues that influenced the mission of the RTL Program were similar to those that influence the research agendas of nearly every organization or agency that supports research in mathematics and science education. Therefore, discussions of the issues that influenced the RTL research agenda may be useful for interpreting the research agenda of other organizations or agencies active in similar areas.
Appendix I

The National Science Foundation's
Program for Research on Teaching & Learning

(Since superceded by other research programs at NSF)

Research that makes a difference

... in theory and practice.

GENERAL PROGRAM GOALS

The National Science Foundation's Program for Research on Teaching and Learning (RTL) is distinctive within the Directorate for Education and Human Resources (EHR) because funded projects focus on delivering knowledge and theory-based prototypes rather than materials, programs, or enhanced human resources. Also, unlike research and development programs in other federal agencies whose goals are to deal with issues that are of general educational, social, and economic significance, and where issues in mathematics and science education are simply treated as special cases, the RTL Program emphasizes issues in which: (a) the quality of mathematics, science, and technology education is a central concern, and (b) distinctive characteristics of mathematics, science, and technology education are highlighted in learning, problem solving, or instruction.

In addition to traditional types of research that emphasize data gathering, data analysis, data interpretation, and hypothesis testing, RTL projects frequently involve activities such as:

- Anticipating problems and needs-for-knowledge before they become impediments to progress.
- Translating future-oriented problems into researchable issues.
- Translating the implications of research and theory development into forms that are useful to practitioners and policy makers.
- Facilitating the development of research communities to focus on neglected priorities or strategic opportunities.

The goal of the preceding activities is to develop a body of knowledge that is theoretically sound, experience tested, and meaningfully instantiated in order to address emerging and anticipated problems in science, mathematics, and technology education. RTL-funded projects
are not simply curiosity driven; they aim at strategic opportunities or significant leverage points for improving educational practice; they are proactive rather than reactive in terms of the problems they emphasize; and, projects that are treated as priorities usually involve much more than simply taking the next step in a productive program of research. Research on teaching and learning is research that makes a difference . . . in theory and in practice.

**RELATIONSHIPS TO OTHER EHR PROGRAMS**

Because only limited funds are available, the RTL Program must focus its resources on projects that emphasize issues and problems that are anticipated to be critical to the success of current and future EHR initiatives. Therefore, to ensure maximum relevance to such initiatives, negotiations for RTL funding typically involve input from, and joint funding with, programs such as:

- State, urban, and rural systemic initiatives.
- Instructional materials development.
- Course and curriculum development.
- Teacher enhancement.
- Teacher preparation.
- Applications of advanced technologies.
- Networking infrastructure for education.
- Advanced technological education.
- Informal science education.

**A MATRIX OF CURRENT FUNDING PRIORITIES**

The matrix that follows identifies areas that are current funding priorities in the RTL Program. The columns are content-specific versions of four general themes: (a) school-to-work transitions in a technology-based society, (b) equity, (c) educational quality, and (d) technology. The rows, as well as their ordering from learners and teachers to learning environments, focus on trends related to the “unit of analysis” that is emphasized in RTL-funded projects. That is, the RTL Program’s traditional strength has been research on the
nature of individual student's knowledge, learning, and problem solving; but, recently, the emphasis has expanded to include research on the nature of teacher knowledge, attitudes, and beliefs about mathematics, science, technology, teaching, learning, and problem solving; and, currently, there is growing recognition that attention must go beyond individual students and teachers to include systemic factors involving groups, learning environments, programs, and implementations.

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<th>Preparation for Success in Postindustrial Societies</th>
<th>Equal Access to Powerful Ideas</th>
<th>Standards &amp; Assessments for Documenting Progress</th>
<th>Influences of Technologies on Teaching &amp; Learning</th>
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**THEORETICAL PERSPECTIVES AND RESEARCH METHODOLOGIES**

RTL-funded research has involved a wide range of theoretical perspectives and research methodologies, borrowing from and building on fields as diverse as cognitive science, sociology, anthropology, economics, and engineering; also, in many areas, mathematical sciences education research has evolved beyond theory borrowing to theory building. For example, the application of cognitive science to mathematics or the sciences is not just a general psychology applied to mathematics and science; rather, it has features that reflect the distinctive characteristics of knowledge, learning, problem solving, and instruction in these domains. Similar trends are apparent in areas evolving out of sociology, anthropology, and other disciplines.

Cognitive psychology has replaced behavioral psychology as the dominant source of theoretical models in mathematical sciences education research. Consequently, students' knowledge (and learning and problem solving) is likened, not to a machine, but to evolving, self-regulating, and adapting organisms. Similar "constructivist" paradigm shifts also have occurred in theories related to the development of teachers, programs, and learning environments.
To accompany the preceding paradigm shifts, the development of appropriate research methodologies is, in itself, a significant product of RTL-funded research. Examples include: teaching experiments in technology-intensive learning environments, computer modeling of complex problem solving behaviors, sophisticated videotape analysis techniques for real-life problem solving situations, and ethnographic observations in which attention is focused on abilities that go far beyond "shopkeeper arithmetic" from the industrial age. Therefore, competitive proposals must take special care to keep abreast of rapid advances in research methodologies and relevant theoretical models, as well as rapid transitions from hypothesis generation to hypothesis testing.

MORE ABOUT THE CELLS IN THE MATRIX OF FUNDING PRIORITIES

For each column of the RTL Program's Matrix of Funding Priorities, this section identifies examples of the kind of issues that are of concern to RTL for learners, teachers, and learning environments.

Preparation for Success in a Postindustrial Society

To live and work in a technology-based society, preparation for success includes much more than simply: geometry from the time of Euclid, algebra from the time of Descartes, shopkeeper arithmetic from the industrial age, elementary logical reasoning from the time of Aristotle, and a few science topics from the time of Newton. The world outside of schools is changing rapidly. The essential characteristic of an information age is that the constructs (conceptual systems, models, structural metaphors) that humans develop to make sense of their experiences also mold and shape the world in which these experiences occur. For example, many of the most important mathematical or scientific "objects" that impact everyday lives are systems—complex, dynamic, interacting systems—which range in size from large-scale communication and economic systems, to small-scale systems for scheduling, organizing, and accounting in everyday activities; and, many of the most important characteristics of these systems require students to go beyond surface-level data that can be counted or measured directly, and to focus on powerful patterns and regularities beneath the surface of
things. Consequently, a primary goal of mathematics and science education is to help students develop powerful constructs (or conceptual technologies) that can provide them with the power to understand, use, create, manipulate, and control these systems for a variety of purposes. and to generate descriptions, explanations, and predictions for purposes that range from simple understanding (to avoid difficulties) to optimization or stabilization.

**Issues Related to Learners.** What kinds of problems and problem solving situations are priorities to address in a world increasingly dominated by complex, dynamic, interacting systems? What knowledge, abilities, and skills provide the most useful foundations for lifelong learning, problem solving, and adaptability, especially when new types of teams, tools, and resources are used to address new kinds of problems within systems that did not exist in the past?

**Issues Related to Teachers.** What knowledge and abilities must teachers develop when it is no longer possible to be an “expert” in every area of student inquiry and when teachers' roles must shift from delivering facts and demonstrating skills toward being professional knowledge guides, information specialists, and facilitators of inquiry? How can teachers maintain a familiarity with the tools, resources, and problems that are priorities for success in the rapidly changing world outside of schools?

**Issues Related to Programs and Learning Environments.** What kinds of programs and learning environments are needed when lifelong learning must replace one-time instruction and certification? When instruction increasingly occurs in response to the needs, experiences, and purposes of individual learners? When the ability to create, seek out, and use information is as important as remembering and repeating facts and rules? When learning can take place anytime, anywhere, with anyone—rather than in rigidly structured spaces and time slots?

**Equal Access to Powerful Ideas**

In a world characterized by increasingly complex, dynamic, and interacting systems (including systems of ideas), people who have not had the opportunity to develop the most powerful elementary but deep constructs in mathematics and the sciences are at a major disadvantage, especially in jobs beyond the entry level. In general, the educational system we have inherited was not designed to prepare students for adaptive functioning in technically complex environments where continuous learning is necessary. For example, its goals seldom
emphasize the ability to explain structurally complex systems, the ability to construct convincing arguments, the ability to use sophisticated tools and resources, or the ability to analyze problems in a way so that they can be addressed by teams with diverse specialties. Therefore, by the time most students complete their K–12 mathematics and science education, they are seldom proficient at describing, explaining, creating, or manipulating elementary systems in which the "objects" go beyond simple counts, measures, and shapes to include entities such as ratios, rates, proportions, coordinates, rules, transformations, propositions, continuously changing quantities, accumulating quantities, or patterns or characteristics of sets of data (rather than isolated pieces of data).

**Issues Related to Learners.** Among the conceptual technologies that have the potential to provide the greatest power in the future lives of most students, which are elementary in spite of their depth, and to what extent are they accessible to all students? How is the development of low-level facts and skills related to the development of deeper or higher-order understandings and abilities? How can the development of deeper and higher-order understandings be stimulated, facilitated, and focused? How can students increase the power and generalizability of the constructs they develop?

**Issues Related to Teachers.** How can teachers shift attention beyond superficial "coverage" of a large number of small ideas (facts and skills) to focus on depth and power for a small number of big ideas (models, conceptual technologies, reasoning paradigms, and unifying themes and principles)? What understandings do mathematics and science teachers need about the ways the most important "big ideas" develop—in time (historically), in polished modern reinterpretations (mathematically, scientifically), in available curriculum materials (educationally), in class (pedagogically), and in the consciousness of students (psychologically)?

**Issues Related to Programs and Learning Environments.** What kind of programs and learning environments are needed to provide democratic access to powerful ideas and to capitalize on the experiences, goals, and learning styles of more than a narrow range of students? What kind of learning environments are needed to encourage students to develop, test, extend, or refine their own increasingly powerful constructs? What alternatives exist to the current layer-cake curriculum that acts structurally as a filter and delays access to the big
ideas of mathematics so that only few students manage to engage those ideas? How can we build curricula that offer more longitudinal coherence and greater gestation time for major strands of mathematical and scientific ideas, such as the mathematics of change or the mathematics of uncertainty and their relationship to scientific processes? Such curricula should offer meaningful access to these ideas for all students.

Standards and Assessments to Document Progress

In a world where new ideas, tools, and resources are being used in new kinds of problem solving situations, past conceptions of mathematical and scientific ability are often far too narrow, low-level, and restricted to provide unbiased guidelines for recognizing and rewarding the abilities and achievements of students, teachers, or programs of instruction. Above all, research on assessment should help clarify the nature of instructional goals. Yet, most existing high-impact standardized tests are poorly aligned with national standards for instruction and assessment and the operational definitions of competence that they presuppose tend to be based on obsolete “industrial age” analogies to the assembly and functioning of simple machines. The negative influence of these assessments on the education system have been widely documented.

Issues about assessment are not restricted to the improvement of testing. Regardless of whether the instruments focus on learners, teachers, programs, or learning environments, educationally responsible assessments should gather information from a representative and balanced variety of sources. The descriptions that are generated should go beyond naive “good/bad” labels to include information about issues such as: Good for what purposes? Good in what ways? Good under what conditions?

Assessment instruments should contribute to both learning and to assessment; they also should have positive instructional value in the sense that they do not take students away from learning, or teachers away from teaching. That is, high-quality assessments should enable students, teachers, and programs to make progress while simultaneously documenting the nature of the progress that is being made. For example: (a) feedback should enable individuals to develop in ways that are continuously better, without reducing goals to overly-simplistic definitions of best, and (b) documentation often can be gathered in ways that produce continuous traces of progress, without relying on naive subtracted differences between pretests.
and posttests (which often embody simplistic and distorted conceptions of actual instructional goals).

*Issues Related to Learners.* In mathematics and the sciences, as well in other areas in which advanced technologies are use extensively, many different kinds of personalities, knowledge, and abilities can lead to success, many different types of success are possible, and most people have irregular profiles of expertise—strengths in some areas, weaknesses in others. Therefore, new forms of assessment are needed that go beyond comparing individuals along one-dimensional good/bad scales to assessments that focus on instruction-relevant strengths and weaknesses.

*Issues Related To Teachers.* One of the primary purposes of assessment is to provide useful information to improve the quality of informed decision making by teachers, students, parents, and others whose goals are to optimize achievement. What information and feedback do teachers need to support wise instructional decision making? What knowledge and abilities should teachers develop in order to recognize and reward a broader range of mathematical and scientific abilities in their students? How can they stimulate and facilitate the development of problem solving personalities that involve productive beliefs, styles, attitudes, and values, as well as specific mathematical or scientific knowledge and abilities?

*Issues Related to Programs and Learning Environments.* In the same way that assessments of students should be integrated seamlessly into learning, problem solving, and instruction, assessments of programs should be integrated seamlessly into implementation, dissemination, and program refinement. It is misleading to label programs “successes” or “failures” as though everything the successful ones did was effective, everything the unsuccessful ones did was not effective. All programs have profiles of strengths and weaknesses. Most “work” for some types of results but “don’t work” for others. Most are effective for some students (or teachers, or situations) but not for others. In general, most work some of the time in some circumstances, but none work all of the time in all circumstances. In fact, characteristics that lead to success in one situation often turn out to be counterproductive in other situations. Therefore, the goals of program assessments should be to facilitate and stimulate continuous development. No fixed and final state can ever be reached as though continuous growth is no longer necessary.
Influences of Technologies on Teaching and Learning

Some educationally relevant technologies relate directly to teaching and learning whereas others are part of the infrastructure that support the management of instruction and communication among teachers, administrators, parents, policymakers, and others. Each type of technology brings a host of research questions regarding its implementation, use, and impact. For example: How may the effects of new tools and environments differ across different populations or across time? How can we best redefine the curriculum to exploit the power of new technologies to democratize access to powerful ideas and ways of thinking? How are emerging technologies changing nature of mathematics and the sciences as well as their uses in society?

*Issues Related to Learners.* Advances in technology have produced dramatic changes in how students are able to learn, what they should learn, what kind of problem solving situations they should be able to address, and what stages of problem solving tend to be emphasized. However, new technological tools, representations, and learning environments not only change the means and goals of learning, they also change the learners themselves. Generalizations that might have been valid for students-without-tools often simply do not apply to students-with-tools. Therefore, careful research is needed to document technology-related changes in thinking, visualization, communication, and problem solving. Research also is needed about how communication technologies may change the ways learners interact productively with one another, with teachers, and with information and data.

*Issues Related to Teachers.* Powerful conceptual technologies are not simply new ways to address old ideas. New types of knowledge and abilities become important, and new levels and types of understanding become important for old ideas and abilities. Furthermore, just as learners are changed by technology, so too are teachers. Indeed, the profession itself is changing. Research on teacher enhancement and preparation must take into account the new technological tools and contexts for the practice of teaching. Especially important is research that deepens understanding about how teachers can exploit opportunities to promote active learning and assessment, and how technology itself can serve the process of this integration into everyday practice.
**Issues Related to Programs and Learning Environments.** Although new technologies have produced radical changes in the worlds of work and entertainment, they have not yet made comparable impact in education. One reason for this lack of impact is that intended technological innovations have tended to be superimposed on an existing sets of practices that were taken as given. Yet, it is clear that realizing the full potential of new technologies must be systemic. It will require deep changes in curriculum, pedagogy, assessment, teacher preparation and credentialing, and even the relationships among school, work, and home. Consequently, RTL-funded research should anticipate possible new circumstances resulting from rapidly changing technologies and it must recognize that the real impact of research is usually several years away. Therefore, such RTL research will take place in the context of the development or deployment of new technologies; and, a question that all proposed projects must confront is: “How might new technologies change what is important to teach and learn as well as how this knowledge and information is taught and learned? How might emerging technologies undermine the importance of anticipated results?”

**FIVE QUESTIONS FOR PEER ASSESSMENTS OF RTL PROJECT PROPOSALS**

1. How significant is the project from the point of view of practice?
   - Is the issue a priority in mathematics, science, & technology education?
   - Is the issue a priority for NSF curriculum reform initiatives?
   - Will the results address an important neglected issue?
   - Are the results likely to make a significant difference?
   - Will the results provide key leverage points for change?
   - Will the results fill a void, or capitalize on a unique opportunity?

2. Is the issue a priority for RTL to address?
   Does the project fit the RTL Program’s distinctive niche compared with other programs inside NSF? compared with other programs outside NSF?

3. Is the project highly significant from the point of view of theory development?
3. RESEARCH AGENDAS

- Will the results significantly advance what is known?
- Are the results likely to make a significant difference?
- Will the results provide key leverage points for change, fill a void, or capitalize on a unique opportunity?

4. Is the methodology clear, appropriate, and sound?
   - Is it clear what the project is going to do?
   - What theoretical framework will be used to select, filter, weight, organize, and analyze data?
   - What patterns and regularities will be investigated?
   - Will the results and conclusions be credible to a skeptic?

5. Is this the right person and place to conduct this particular project?
   - What is the track record or the PI, staff, and organization?
   - past influences on nationally significant efforts.
   - contribution of “big ideas” to other projects.
   - contribution of (former or current) staff to other projects or efforts.