DOCUMENT RESUME

ED 478 918 SE 068 281

AUTHOR Linn, Marcia C.; Kessel, Cathy; Lee, Kristen; Levenson, Janet; Spitulnik, Michelle; Slotta, James D.

TITLE Teaching and Learning K-8 Mathematics and Science through Inquiry: Program Reviews and Recommendations.

INSTITUTION North Central Regional Educational Lab., Naperville, IL.

SPONS AGENCY Office of Educational Research and Improvement (ED), Washington, DC.

PUB DATE 2000-10-31

NOTE 26p.

AVAILABLE FROM NCREL, 1120 E. Diehl Road, Suite 200, Naperville, IL 60563-1486. Tel: 630-649-6594; Fax: 630-649-6700; Web site: http://www.ncrel.org.

PUB TYPE Reports - Research (143)

EDRS PRICE EDRS Price MF01/PC02 Plus Postage.

DESCRIPTORS *Curriculum Design; Elementary Education; *Lifelong Learning; Mathematics Instruction; Middle Schools; Science Education

ABSTRACT

This report offers guidance for those shaping policy and designing elementary and middle school science and mathematics courses that prepare students to be lifelong users of scientific and mathematical ideas. We have reviewed programs designed to improve elementary and middle school students' understanding of science and mathematics by incorporating instructional technology effectively into the curriculum. Using criteria backed by research on learning and instruction, we have selected exemplary programs from among those reviewed. We emphasize the teaching of science and mathematics as a process of inquiry in which students learn to solve complex problems and critique scientific and mathematical arguments. We look for uses of computer and communications technology that help students become lifelong science and mathematics learners who are prepared to meet all sorts of challenges from computing their income taxes to interpreting data on global warming to assessing the risk of a medical procedure. We discuss: (1) Contemporary views of teaching and learning mathematics; (2) Promising uses of technology in learning and instruction; (3) Evolving uses of technology in science and mathematics; (4) Criteria for selecting exemplary instructional programs; (5) Reviews of programs that meet our mandatory requirements, organized by category; (6) Recommendations of exemplary programs; and (7) next steps. (Author)

# Teaching and Learning K-8 Mathematics and Science Through Inquiry: Program Reviews and Recommendations

**Marcia C. Linn, Ph.D.**
**Cathy Kessel. M.A.**
**Kristen Lee, M.A.**
**Janet Levenson, M.A.**
**Michelle Spitulnik, Ph.D.**
**James D. Slotta, Ph.D.**

**Oct. 31, 2000**

## Contents



## I. Introduction

This report offers guidance for those shaping policy and designing elementary and middle school science and mathematics courses that prepare students to be lifelong users of scientific and mathematical ideas.

We have reviewed programs designed to improve elementary and middle school students' understanding of science and mathematics by incorporating instructional technology effectively into the curriculum. Using criteria backed by research on learning and instruction, we have selected exemplary programs from among those reviewed.

We emphasize the teaching of science and mathematics as a process of inquiry in which students learn to solve complex problems and critique scientific and mathematical arguments. We look for uses of computer and communications technology that help students become lifelong science and mathematics learners who are prepared to meet all sorts of challenges-from computing their income taxes to interpreting data on global warming to assessing the risk of a medical procedure.

We discuss:

- Contemporary views of teaching and learning mathematics
- Promising uses of technology in learning and instruction
- Evolving uses of technology in science and mathematics
- Criteria for selecting exemplary instructional programs
- Reviews of programs that meet our mandatory requirements, organized by category
- Recommendations of exemplary programs
- Next steps

**Contemporary Views of Teaching and Learning Mathematics**

Cognitive and social research clearly indicates that educational programs should challenge students to link, connect, and integrate their ideas and to learn in authentic contexts, taking into account their perception of real world problems. (Baumgartner & Reiser, 1998; Bransford, Brown and Cocking, 1999; diSessa, 2000; Linn & Hsi, 2000; Slotta & Linn, 2000). Too often our science and mathematics curricula present ideas in isolation, fail to encourage students to link their ideas, settle for the regurgitation of facts rather than the connection of ideas, and fail to prepare students to solve the personally relevant, everyday problems they will encounter throughout their lives. Instead, we should be educating students to be lifelong learners of science and mathematics by engaging in the process of inquiry that is the very nature of these fields.

National groups have recently set standards for learning and teaching in science and mathematics that emphasize inquiry. In science, two reports detail standards for instruction in elementary and middle school. The Project 2061 benchmarks from the American Association for the Advancement of Science, (AAAS, 1993) and the National Research Council Science Education Standards (NRC, 1996) both offer a philosophy of instruction as well as specific topic suggestions for each grade level. The National Council of Teachers of Mathematics (NCTM) revolutionized thinking about mathematics instruction with the publication of standards (NCTM, 1989). These reports emphasize the need for understanding the scientific process as well as the integrated nature of science and mathematics. They advocate problem-based instruction as well as assessments that are integrated with instruction.

NCTM called for significant increases in approaches to teaching and learning that foster mathematical inquiry, such as problem solving, critiquing, and project work. These standards influenced the development of many National Science Foundation (NSF)-funded curriculum projects during the '90s. NCTM published an update and elaboration of its standards in 2000 that incorporated new research on teaching and learning (NCTM, 2000). NCTM recommended that all high school students receive four full years of mathematics instruction and identified specific instructional strategies for fostering a thorough understanding of mathematics. NCTM's updated report pays greater attention to the role of instructional technology. The NCTM maintains a Web site with materials that meet the new criteria and "e-examples" that illustrate the current standards, as we describe below.

The NCTM sees clear advantages for technology, commenting, "Students can learn more mathematics more deeply with the appropriate use of technology (Dunham and Dick 1994; Sheets 1993; Boers-van Oosterum 1990; Rojano 1996; Groves 1994). Technology should not be used as a replacement for basic understandings and intuitions; rather, it can and should be used to foster those understandings and intuitions" (NCTM, 2000, p. 25).

The NCTM sees technology as enhancing opportunities for students with special needs. For example, the NCTM notes, "Technology can help students develop number sense, and it may be especially helpful for those with special needs. For example, students who may be uncomfortable interacting with groups or who may not be physically able to represent numbers and display corresponding symbols can use computer manipulatives. The computer simultaneously links the student's actions with symbols. When the block arrangement is changed, the number displayed is automatically changed. As with connecting cubes, students can break computer base-ten blocks into ones or join ones together to form tens" (NCTM, 2000, p. 81).

The NCTM identifies specific uses of technology for inquiry (e.g., place-value concepts can be developed and reinforced using calculators). The NCTM emphasizes using calculators to identify patterns, pointing out, for example, that, in "a challenging calculator activity for second graders... students begin at one number and add or subtract to reach a target number. By having students share and discuss the different strategies employed by members of a class, a teacher can highlight the ways in which students use place-value concepts in their strategies"(NCTM, 2000, p. 81).

Computers and scientific or graphing calculators permit middle-grade students to deal with "messy," authentic problems. Combined with electronic data-gathering devices, such as calculator-based laboratories, these tools allow students to gather and analyze data on such topics as the water quality of a local stream. The NCTM points out, "For example, students might be interested in investigating whether it is cost-effective to recycle aluminum cans at their school, or they might explore weather patterns in different regions. Graphing calculators and easy-to-use computer software enable students to move between different representations of data and to compute... with messy numbers, both large and small, with relative ease" (NCTM, 2000, p. 258).

Science and mathematics educators have also stressed the importance of age-appropriate instruction. Piaget (1929), Vygotsky (1978) and others have identified developmental trajectories and their impact on learning, stressing that instruction builds on what students know and is regulated by the developmental process. Recent research has established that student trajectories vary depending on a huge range of factors, including prior schooling, family experience, and personal interest. Rather than setting definite age-appropriate tasks, it has become important to test instruction with the intended students and tailor instruction to student ideas. If the instruction is to succeed, it must address the ideas students already have about scientific or mathematical topics. For example, most students come to science class with the idea that heat and temperature are the same thing, since the terms can often be used interchangeably. Instruction must take this confusion into account and address it directly (Linn & Hsi, 2000). Many of the technological environments reviewed in this report enable teachers to customize instruction to their students and to regularly update their own versions of activities as they gain more insight into the student audience.

At the same time that educators and others are becoming aware that technology can improve instruction, a large body of national and international test results has revealed weaknesses in students' preparation and in their understanding of both basic and advanced scientific and mathematical ideas. Large numbers of students have difficulty solving complex problems in science and mathematics and fail to understand the process of inquiry. American students fall further and further behind their international counterparts as they progress through the educational system. The *Third International Mathematics and Science Study* (TIMSS) reports that, by eighth grade, American students have fallen from near the top in fourth grade to around the middle among the more than 40 countries studied, when their scientific and mathematical accomplishments are compared (Schmidt, McKnight, & Raizen, 1997; Schmidt et al., 1999; Stigler & Hiebert, 1999; U.S. Department of Education & National Center for Education Statistics, 1999). These results, as well as other research about how students learn, have motivated teachers, schools, policy analysts, and concerned citizens to call for reform of instruction.

Because education is a complex, interconnected system, change is difficult. Many attempts at innovation succumb to the pressures of the status quo, becoming indistinguishable from the programs they seek to replace. For example, an innovative approach to problem solving may evolve into just another electronic "drill and kill" program by the time it becomes available to educators as a product. In this report, we look for exemplary programs that help to transform the teaching of science and mathematics based on current research studies.

Current research offers guidelines for taking advantage of what we know about how people learn. A recent National Academy of Sciences committee has produced *How People Learn*, an extremely clear and powerful summary of research on student learning (Bransford, Brown, & Cocking, 1999) that emphasizes weaknesses in the current educational system as well as research results pointing to reforms that could improve student outcomes.

Comparing the teaching of middle school mathematics in Japan with instruction in the United States underscores some of the shortcomings of American education. In a report synthesizing classroom observations conducted as part of the TIMSS study, Stigler and Hiebert (1999) noted that over 95% of American in-class work requires only that students apply an approach demonstrated by the teacher. Less than half of the class time in Japan is devoted to this sort of work. In contrast, Japanese students spend far more time on complex science and mathematics and generally start a topic by inventing a strategy for solving novel problems. American students study less demanding topics and generally start by reading about or listening to the correct way to approach the problem. In the 1980s, Stevenson, Stigler, and their colleagues studied first and fifth graders in Japan, Taiwan, and the United States using tests and individual interviews (Stigler, Lee, & Stevenson, 1990). On average, Japanese students outperformed Taiwanese students, and Taiwanese students outperformed U. S. students on these tasks. Essentially, the Japanese curriculum offers students more opportunities for scientific and mathematical inquiry, while the American curriculum asks American students to spend most of their time learning established approaches.

The TIMSS analysis of the textbooks used in American science and mathematics courses supports the classroom investigations from the TIMMS research. The U.S. curriculum, as reflected in recent textbooks, is "a splintered vision" (Schmidt, McKnight, & Raizen, 1997). Project 2061 (Kulm, 1999; Roseman, Kesidou, Stern & Caldwell, 2000) recently released an analysis of middle school textbooks for science and mathematics and rated most as falling short of emphasizing inquiry and helping students develop cohesive understanding. Textbooks did not offer sufficient opportunity for students to understand science and mathematics so that they could apply the ideas to novel and complex problems. These analyses coincide with complaints from the workplace that American students lack preparation for jobs requiring scientific and mathematical thinking.

Science and mathematics instruction in the elementary and middle school has often resulted in fewer opportunities for females and members of various cultural groups. Two factors contribute to this problem. First, stereotyped beliefs about who can succeed in science and mathematics deter some from participating in the discourse of mathematics and science (AAUW, 1998; Fennema & Leder, 1990; Hyde, Shibley, Fennema, Ryan, Frost, & Hoop, 1990; Martin, 2000; Sadker & Sadker, 1994). Second, and more importantly, traditional classroom activities and dull assignments reduce motivation and stand in the way of lifelong science and mathematics learning (Fennema & Leder, 1990). Often, science and mathematics problems are placed in contexts that make little sense to students, such as those involving frictionless surfaces, gear ratios or trains traveling in different directions. Students cannot connect these problems to their own experiences and have no reason to use the ideas again. The likelihood of everybody succeeding is enhanced when instruction allows students to select personally meaningful projects and activities-an option that technology can support and encourage. Successful equity programs improve instruction for all students and have the greatest impact on those who are at greatest risk for learning less. When the science or mathematics curriculum is personally relevant to individuals and emphasizes complex projects rather than skill-based exercises, more students can become lifelong learners because their motivation is increased.

There is considerable concern about when and how young children should use technology. To clarify a discussion that has often been heated, we attempt in this report to focus attention on best practices in the use of technology. Today, many young children use technology for games at home and for skill development activities that often have a game-like character at school. Older students often use technology for chat and e-mail as well as for electronic purchases. To promote inquiry, as the NCTM, AAAS, and NRC suggest, technology could be used to test conjectures, construct objects, develop concepts such as the number line, distinguish among competing arguments, and animate functional relationships. Concerns and recommendations about the use of technology need to take these different uses into consideration.

One issue concerns social interactions and technology. Several recent surveys report that family members are spending slightly more time conversing over e-mail and less time in face-to-face communication due to the increased use of technology. Depending on how technology is used, it can increase or reduce the frequency of face-to-face discussion of mathematics and science. In schools, when students use skill development programs, they often work alone on a computer, much as they would if doing problem sets at their desks. In contrast, for project-based mathematics and science, students generally work in groups of two or more at the classroom or laboratory computers. Project work typically increases the scientific and mathematical discourse in the classroom and, when students work in groups of two, also ensures that males and females have equal contributions to the discussion (Linn & Hsi, 2000). Overall, opportunities to use computers for instruction have increased opportunities for students to interact with each other about academic topics and have also allowed teachers to talk more to small groups of students rather than lecture to large groups. When teachers talk to small groups they can tailor their message more effectively and have a greater impact on learning.

Another issue concerns using technology in projects versus using other materials, such as construction kits or hands-on experiments for projects. Many of the titles we have identified demonstrate the benefits of combining technology and other materials to make projects even more successful. For young children, for example, programmable bricks combine technological and equipment-based construction. For older children, modeling environments such as Model-It combine the strengths of technology with opportunities for personal data collection.

Another issue concerns the amount of time that children spend with technology. Since students could have very different experiences while spending the same 10 hours per week using technology, watching television, or reading, establishing arbitrary limits seems difficult. Consider watching television. One student might learn about first hand accounts of the Civil War on the history channel, another might develop a serious interest in the habitat of the elephant from a public television program, and another might sing along with the latest rock tunes on MTV. The same is true for using other technologies. Using technology could involve reading, playing games, doing projects, developing spatial reasoning ability, or watching adventure videos. We encourage teachers and families to carefully monitor the uses of technology to ensure that students have balanced opportunities for leisure and academic activities. Schools and families should make careful decisions about which uses of technology they employ and how those technologies fit into the totality of a child's activities.

Another serious concern is repetitive stress injury. Recent research has shown that some adults and some children spend large amounts of time playing electronic games, engaging in chat, or conducting work-related activities. We are very concerned about ergonomically safe uses of technology in schools. When computers became widespread in the workplace, many individuals developed repetitive stress injuries as a result of inappropriately designed workspaces. Schools can learn from this experience and carefully design the environments where computers are used to ensure that students are not at risk for repetitive stress injuries. In addition, awareness among families and schools about repetitive stress injuries will help ensure that both home and school use of technology is safe and sensible.

Determining when and how to incorporate technology into the curriculum has concerned curriculum designers and policy analysts alike. Every learner will encounter new technologies and will need to learn new applications. Preparing students to be fluent users of technology in their lives must take into account the activities that students are likely to undertake. Only careful planning can ensure that students learn relevant technologies and develop the capability to adapt to the variety of technologies that will be relevant to their career and their life.

Access to technology in science and mathematics raises an issue currently referred to as the "digital divide." Although the digital divide between older and younger Americans is narrowing, the divide between wealthier and poorer individuals and schools remains large. Wealthier schools offer their students greater access to instructional and communications technology than poorer schools. Wealthier schools also have greater resources for purchasing software and for providing professional development. It is no surprise, then, that many reports suggest that inquiry opportunities in science and mathematics are far more common in the wealthier schools.

Schools bring older and younger populations together in ways that might eventually help to resolve the problem of the "digital divide." School and community programs offer one of the best ways to reach those whose economic situation keeps them from becoming fluent with technology. However, people need more than a few hours per week of access to computers to become fluent in their use, and most school programs can offer no more exposure than this. Access to a computer for a weekend could give a student a six-month advantage over someone whose only access to computers is in a class. We must address this issue in order to prepare all learners—young and old, rich and poor—to be fluent users of technology and to succeed in the workplace.

Infusing the curriculum with technology can increase the effectiveness of science and mathematics instruction. Research in classrooms, reviews of the curriculum, studies of learning, and investigations of professional development all point to the need for widespread, cumulative reform of the educational enterprise (Athens & Cohn, 1999; Schmidt, McKnight, & Raizen, 1997; Schmidt et al., 1999; Stigler & Hiebert, 1999; U.S. Department of Education & National Center for Education Statistics, 1999). Recent research looking closely at how students learn in classrooms has revealed many obstacles that prevent students from developing their own scientific and mathematical understanding. Too often, problems are presented in isolation, students are not encouraged to look for patterns, and instruction emphasizes right answers, rather than critical appraisal of the methods used to solve problems. Technologically enhanced curricular materials can address these shortcomings in the traditional curriculum while enabling students to think scientifically and mathematically.

**Promising Uses of Technology in Learning and Instruction**

New programs that make effective use of technology not only offer promising instructional opportunities, but also present challenges for professional development, since they depart from traditional practice in many ways.

Technology is not a panacea guaranteed to improve test scores. Neither is it an option reserved exclusively for students in multimedia or computer programming courses. Rather, current technological innovations offer education two major opportunities: to increase the role of inquiry in the classroom and to prepare students for a world in which technology will play a larger and larger role in their lives. The best gift we can give this generation of students is to offer them courses that enable them to become lifelong science and mathematics learners and to add new technological resources regularly to their repertoire.

There is widespread agreement that students will benefit from learning with and about technology in science and mathematics instruction. Nevertheless, effective incorporation of information technologies into the curriculum has been controversial, difficult, and demanding. Many have worried that students might become dependent on calculators, computers, or other computational aides, and thereby not learn the fundamental facts and concepts of science and mathematics. Others worry that students will spend inordinate amounts of time learning new technologies-time that could be better spent learning the science and mathematics itself. Finding ideal uses of technology in science and mathematics instruction remains an active research area, and the technology itself is a "moving target," as new projects emerge on a regular basis. The recommendations in this report capture current practices and research findings and will require regular revision as new tools and new research results become available.

The disciplines of science and mathematics have always employed a vast array of technological tools for research, everyday activity, and education. Historically, science and mathematics have employed the sundial, the reckoning board, the abacus, the aqueduct, the astrolabe, the lever, the sextant, the slide rule, the calculator, the computer, the Geiger counter, data collection tools, and manipulative materials, such as blocks or three-dimensional solids. Additionally, the technologies for science and mathematics have constantly become more powerful and more useful for solving equations, visualizing complicated surfaces, or working with dynamic systems.

The National Research Council recently called for the teaching of "fluency with information technology," by incorporating appropriate technologies at each grade and course level (NRC, 1999). Standard setting groups for educational programs from kindergarten through elementary and middle school strongly recommend using technology to promote understanding of science and mathematics and to prepare students for new technologies as they become available.

Adding technology to science and mathematics instruction has the danger of intensifying inequitable stereotypes and reinforcing the view that these are male domains; however, if used effectively, technology can connect science and mathematics to problems that interest individuals who have been historically underrepresented in science and mathematics careers (AAUW, 2000). Some programs have demonstrated that technological tools can be a force for equity in science and mathematics learning, because they permit more personalized and project-oriented undertakings (Linn & Hsi, 2000). Technology also can help teachers introduce disciplines, such as statistics and climate modeling, that connect to a broader array of courses of study. Technology can increase success for all students by making teachers more effective, by reducing mundane, repetitive tasks, by offering help on logistical details, and by freeing teachers to spend their time working with individuals and small groups.

Until recently, enthusiasm for technology in schools has manifested itself in a focus on new wiring and new equipment. Too often, we have neglected the supports needed for schools and teachers to become fluent users of technology and effective designers of science and mathematics programs. Many programs for schools and teachers focus on learning skills such as word processing rather than on developing the capability to be lifelong learners with and about technology. The National Research Council's report on "Fluency with Information Technology" (or FITness) stressed that skills and concepts are not sufficient and that we need to prepare everyone to use technology in their intellectual work. For teachers and schools, this intellectual work includes incorporating technology effectively, testing and customizing new curriculum materials, critiquing innovations, analyzing students' use of technology, and regularly updating personal understanding of technology-enhanced materials. To develop these capabilities, teachers must have the time and the opportunity to explore and reflect on the role of technology in education.

Effective use of technology in instruction requires what has been called a continuous improvement model of instruction. In this approach, teachers regularly evaluate their teaching and revise their approach both to take advantage of new technologies and to tailor instruction to their students. This process involves examining how students use technology and tailoring their programs to build on students' ideas. This is a constant challenge, as each new group of students comes along with more sophisticated understanding and, at times, more experience than the school leaders in some aspects of technology, such as searching for information, playing electronic games (often with complex animation), or participating in on-line discussions. Responding to students' expertise at various levels and directing their energy to scientific and mathematically powerful uses of technology may mean modifying or augmenting an educational program that employs technology.

Programs that teachers can customize easily have a greater potential for success than those where little customization is possible. One aspect of customization is identifying problem contexts that meet the needs of students and incorporating them into instruction. In particular, students benefit when they use science and mathematics for tasks that are important to them in their environment, such as determining a budget for the school play or evaluating the cost-effectiveness of a computer laboratory upgrade.

Technology presses us to rethink science and mathematics instruction for many reasons. Some of the more sophisticated computer applications, such as real-time graphing, give students the opportunity to learn more sophisticated problem-solving strategies than they could without technological support. In addition, technology can engage students more deeply in scientific and mathematical inquiry, which departs from the traditional notion of science and mathematics instruction and challenges teachers and schools to redesign their whole curriculum. New standards for science and mathematics understanding include technological tools as part of the practice of science and mathematics rather than as optional activities. This is one more reason for schools to rethink science and mathematics instruction. Schools need to consider technology in the context of all the course offerings, balance the addition of new technologies with the benefits of reusing programs in new courses, and ensure that students gain lifelong fluency with technology in science and mathematics.

It is not enough simply to introduce these promising curricular materials without also finding solutions to logistical problems and implementing powerful programs for professional development. Indeed, it has been difficult to evaluate some innovations because effective environments for teaching and powerful professional development programs were not in place. Rapidly changing technologies and the availability of wireless networks and portable computers for classroom use not only provide new opportunities but also point to the need for continuously revisiting logistical arrangements for using technology in instruction.

Currently, wireless networks, combined with portable computers, enable schools to place computers on carts to equip classrooms with student computers. Schools can then share these resources among teachers. This advance reduces the need for computer laboratories and enables teachers to incorporate technology more seamlessly into their everyday practice.

Professional development programs are emerging that prepare teachers to truly teach with technology rather than to use computers for personal productivity. Teachers and students both need to understand information technology and its benefits for learning. Teachers, especially, need what is called pedagogical content knowledge. By pedagogical content knowledge we refer to knowledge about how students learn mathematics and science from materials infused with technology. For example, to teach functions with a graphing program or help students understand temperature variations over time, teachers need to understand the potential confusions their students might develop that could interfere with success. . Studies of students interpreting graphs reveal that some students see graphs as a picture rather than a relationship (Leinhardt & Zaslovsky, 1990). Similarly, to teach science with real-time data collection means that we need to understand how students will deal with erroneous data points and how they will detect failures in the equipment. Understanding and anticipating these confusions prepare teachers to be effective in supporting their students as they use technology.

The continuous improvement model of professional development described above enables teachers to refine their pedagogical content knowledge as they teach a topic for a second, third, or fourth time. Ideally, teachers will have an opportunity to experiment with innovative programs that use technology to help them reflect on their practice and continuously improve their instruction. In situations where powerful technological programs have been combined with opportunities for continual improvement, the combination has yielded substantial benefits for learning and instruction (Linn & Hsi, 2000). This approach has proven successful for Japanese teachers following a lesson study approach (Lewis & Tsuchida, 1998) At present, however, there are many obstacles to creating these opportunities, and, for many teachers, the promise of technology remains just a promise.

**Evolving Uses of Technology in Mathematics**

Technology offers challenges and opportunities to those designing programs for the learning and teaching of elementary and middle school science and mathematics. New technologies are changing the nature of science and mathematics research, offering new approaches for learning, changing the definition of basic skills, and enhancing opportunities for instruction. Judicious incorporation of technology into elementary and middle school instruction can prepare all students for lifelong learning of science and mathematics and enable them to use technology throughout their lives to improve their success with science and mathematics.

Depending on one's field of interest, today, one uses very different technologies for scientific and mathematical tasks. In science and mathematics, experts use a vast array of technologies, including four function calculators, graphing calculators, spreadsheets, three dimensional modeling, molecular visualization, and symbolic algebra programs. Since resources such as these change rapidly and are demanding to learn, schools are well advised to incorporate them in a way that enables students to reuse the same application from course to course.

Ideally, instruction would feature software useful for most learners, as well as software tailored to students in specific courses. When students become adults, they will need to budget and plan their own financial activities and ask intelligent questions about issues affecting their life and health. To prepare for these adult activities, every student should receive instruction that provides a foundation for carrying out a series of computations and for critiquing a scientific argument. Learning to use the Internet for information about such issues as climate change or nutritional supplements will ensure that students will later have the skills to carry out personally relevant research investigations and to reflect on what they learn.

The realities of life today suggest the need to revise elementary and middle school curricula to incorporate topics not heretofore considered to be part of the elementary and middle school repertoire, such as spatial reasoning and visual representation of ideas. Several programs reviewed here take advantage of spatial reasoning, including the Geometer's Sketchpad, Stagecast Creator, and AgentSheets. Today, visual representations are more and more prevalent in electronic media, and these representations can communicate about complex contemporary issues such as environmental stewardship and design of universal access facilities. Incorporating spatial reasoning into the precollege curriculum and creating promising technologies to support instruction require serious revision of current practices, as well as refinement of existing technological tools.

Technologies for visualization and modeling have transformed some fields of science and mathematics and seem promising for elementary and middle school instruction. Recent research demonstrates that animation of complex relationships, such as graphs of change over time, connections between components of a geometric construction, and location of a local minimum in a three-dimensional surface can help students learn these difficult topics (Confrey & Mahoney, 1996; Linn & Hsi, 2000; Schwartz & Yerushalmy, 1993). At the same time, considerable research demonstrates that all animations are not successful. Often animations fail because they are too complex or too difficult to understand (e.g., Ainsworth, Bibby, & Wood, 1998).

Technology can provide support for students by offering help or guidance for complex investigations. Well-designed help or guidance can help students figure out alternatives, even while they carry out complex projects or use open-ended modeling environments (e.g., Begel, 1998, 1999; Koella & Hofer, in press). Learning environments, like the Web-based Integrated Science Environment (WISE), enable teachers to spend more of their time in face-to-face interaction and less time "managing," since the software helps students organize their investigations and determine next steps on their own. This advance is an opportunity for students, as well as for teachers, since teachers often avoid projects, unless they have additional classroom support; and students need to learn to use available guidance and help systems in many different software applications.

**Criteria for Selecting Exemplary Instructional Programs**

Some innovative and effective programs that incorporate technology go a long way toward achieving the kind of understanding of scientific and mathematical concepts that standard-setting groups call for; however, technology is not in and of itself a panacea. Considerable research and investigation in classrooms are needed to fully realize the promise of technology for science and mathematics instruction.

Technology is a relatively new player in the educational enterprise, and there are both successes and failures among the experiments that have been undertaken. In this report, we identify promising directions for technology use and link those to recommendations for student understanding.

The programs we selected for review in this report met five mandatory criteria and five pedagogical criteria.

**Mandatory Criteria**

The mandatory criteria helped us select programs that could meet the pedagogical criteria. We define mandatory criteria below.

*Engage students in scientific and mathematical inquiry.* We selected programs that stimulated scientific and mathematical inquiry by requiring students to investigate scientific and mathematical problems and actively build understanding of scientific and mathematical ideas. Inquiry instruction engages students in complex, sustained, reflective reasoning about a problem that involves science and mathematics. Inquiry activities require students to come up with solutions, test their ideas, revise their solutions, select among methods for solving problems, and criticize solutions generated by others. Often inquiry activities involve refining the definition of a problem or require students to generate problems on their own. Commonly inquiry activities take place over days and weeks and involve critical review by peers followed by revision of solutions.

*Focus on science and mathematics content.* We selected programs that taught science and mathematics content appropriate to the grade level of the students as reflected in standards documents. We defined science and mathematics content broadly to include concepts such as risk assessment, nutrition, and probability. We sought programs where science and mathematics were used in solving problems relevant to the lives of students to ensure that students would experience the complexity of applying scientific and mathematical ideas in practice.

*Be appropriate for elementary and middle school students.* We sought programs appropriate for elementary and middle school students. We examined both the content and the sophistication of the technology in making this assessment.

*Use information technology for inquiry teaching and learning.* We sought programs that incorporate technology into instruction rather than "bolt" it on as an adjunct. Programs that mentioned optional use of calculators or computers were not reviewed unless they included specific, novel uses for the technology.

*Be supported by research.* We sought programs with published research on their effectiveness or programs that were designed based on research findings. We included both research reports and testimonials from users of the materials. Although we found the testimonials challenging to evaluate, they helped us understand some of the obstacles and opportunities teachers encounter in using the programs. We recognize that curriculum is only a part of the success of science and mathematics instruction; teachers have a substantial impact on program success, and their reflections help us understand especially the impact of school context on use of innovative technology as well as on innovative curricula (Borko & Putnam, 1996; Ma, 1999; Stigler & Hiebert, 1999).

**Pedagogical Criteria**

Criteria that implement the pedagogical research described above were used to select the most promising programs. Taken together, these criteria describe an educational program that encourages the linked, connected, and generative understanding called for by standards groups and described in *How People Learn*. A large body of research shows the benefit of these innovative curricula (e.g., Bransford, Brown, & Cocking, 1999; Linn & Hsi, 2000; Ma, 1999; Stigler & Hiebert, 1999).

We sought exemplary implementations of these criteria, and we discuss how the programs selected implement one or more of these ideas. Ideally, a full course curriculum would use all of these approaches to reach every student. An individual activity might use one or more of these approaches to achieve overall pedagogical success.

*Be personally relevant to students (academically, practically and intellectually).* We selected programs that connect to the lives of students and increase the likelihood of lifelong learning. Research shows that when educational programs connect to problems that interest students they are more motivated and also revisit the ideas in subsequent personal or educational problem-solving situations (Bransford, Brown, & Cocking, 1999; Linn & Hsi, 2000; NRC, 1999). The NCTM i-Math series includes examples from a broad range of disciplines and from situations that students are likely to encounter.

*Encourage connections among the many disciplines of mathematics and science.* We selected programs that make explicit connections to other disciplines, thereby increasing the relevance of science and mathematics for students. We sought multidisciplinary examples, since most often students will conduct an inquiry that includes concepts and principles from multiple fields.

*Use technology to enhance understanding.* We sought uses of technology that add value to instruction. In some cases (Geometer's Sketchpad and Model-It, for example), technology makes scientific and mathematical concepts or ideas more visible. In other cases, technology increases opportunities for teachers or students to explain concepts more effectively (e.g., the WISE project).

*Meet needs of diverse populations and enable all students to achieve.* We sought programs that teachers can customize and personalize to meet the needs of all the students in their classes. Research shows that students benefit when teachers can tailor instruction to the prior and subsequent lessons in the curriculum and can include varied activities to connect to the best learning strategies for all students (Bransford, Brown, & Cocking, 1999). Programs address this criterion in various ways. Some make sure that all students succeed by carefully monitoring performance, as is the case for Millie's Math House. Others, like MMAP, engage students in diverse tasks and offer multiple representations to help each student participate effectively. Still others, like StarLOGO, offer projects that students can tailor to their interests and resources.

*Support peer learning.* We looked for programs that engage students in collaborative problem solving or in critical review of the work of others. Collaborative opportunities give students the chance to engage in scientific and mathematical discourse and to hear the ideas of science and mathematics in the vocabulary of their peers. Working with peers can also motivate students to persist in activities that they might otherwise abandon, because they feel commitment to the group. Collaboration can also reinforce stereotypes and therefore needs to be monitored carefully (Linn & Hsi, 2000). Programs such as WISE and Jasper use a collaborative approach, as does Mathematics in Context, Connected Mathematics, and Investigations (TERC).

## II. Caveats

We relied on the effectiveness information that was available in published materials. We encouraged testimonials from teachers who were asked to send us messages by the program developers. We also contacted teachers in local districts and asked for recommendations. We would have preferred to have more extensive research about nearly every program, but, with the rapid change of technology, this research is generally not available.

We sought to review all the major projects available for elementary and middle school science and mathematics instruction. In many cases materials mentioned at Web sites or compiled by school districts were difficult to locate. We did not review programs if the software did not work, if materials were not supplied when ordered, or if materials were unavailable to us.

Several categories of materials were considered for review but not included. We did not include programs designed primarily for the home market since these were typically more geared to entertaining than to encouraging inquiry. We also left most games off the list, although some do require mathematical reasoning. Neither of these types of programs connects easily to the curriculum and both are easily converted into activities that do not use inquiry.

We find sites that offer problems of the week promising but not sufficiently infused with technology at the current time. These sites offer challenging problems and some problems that could be enhanced with the use of technology. However, incorporating technology is left exclusively to the teacher or student.

We cannot guarantee the accuracy of the science and mathematics in the software or materials that we reviewed, although we did not encounter any obvious errors. In general, software designers do not make the algorithms they use for computation explicit, so accuracy cannot be assessed. In some cases there are disputes in the field—such as concerning the algorithms that should be used in symbolic algebra programs.

We relied on published accounts of professional development programs and mechanisms for teacher support. We cannot guarantee the effectiveness or quality of these programs, since we have not participated in them.

Many Internet-based programs include advertising on sites that students use. We encourage teachers and schools to develop policies about advertising and to review materials carefully to determine the extent and nature of advertising.

Finally, information about publishers may change due to business mergers and acquisitions within the publishing industry. This may also affect the professional development resources offered in conjunction with particular projects.

## III. Program Reviews

Program reviews are based on reports in the published literature. To the extent that information was available, we include the following information about each project:

*Contact information*: includes Web sites, mailing addresses, and project representatives, if available.

*Description*: describes the age group (e.g., grade) of students, the topics in the curriculum, the basic methodology of the project, the duration of the instruction, and the nature of the units. This section also summarizes the project's theoretical framework for learning and instruction, if any, and reviews the project's historical underpinnings, if relevant, the assessment strategies, if available, and classroom management issues, if described.

*Effectiveness*: reviews research that demonstrates the program's benefits, summarizing published results, including teacher reactions and student reactions, focusing on rigorous studies of learning. Effectiveness may be measured in various ways, from in-depth interviews to large-scale studies of student achievement.

*Professional Development*: reviews the approaches associated with the program. Does the project offer new teacher-users training to help them use the program effectively. Do teacher-training programs accompany the project? Is the training at extra cost? Are there ongoing supports for teachers who are adopting the project?

*Cost and Technical Requirements*: estimates probable program costs and describes the technological requirements for schools (e.g., Internet connections, modern computers, CBLs, VCRs), students (e.g., good typing or computer skills), and teachers (e.g., Web-savvy).

*Implementation*: suggests the conditions under which the program should be implemented if it is to be effective, including technological requirements in and out of school, level of technical support required, and necessary professional development.

### Program Categories

In conducting our reviews, we first identified promising programs through an extensive survey of teachers and technology specialists, review of existing research and research synthesis, examination of recommendations from professional organizations including AAAS, review of winners of various software awards, reviews by government expert panels, and extensive Web searches. These initial surveys of the field provided us with a large set of candidate programs, from which we selected the projects according to the criteria outlined above. As we conducted our reviews, we identified categories consistent with the enGauge framework and represented in available programs.

To organize our recommendations of exemplary programs, below, we defined the following categories: (1) Comprehensive Courses, (2) Project-Based Curricula and Collaborative Projects, (3) Activities and Skill Acquisition, (4) Computational and Representational Tools, and (5) Reviewed Web Sites. These categories correspond to specific locations in the enGauge framework as indicated within the descriptions below. For each of these categories, we provide a brief introduction, make connections to the framework, list the projects we reviewed in table form, and present our reviews of any exemplary projects in the category.

### Recommendations of Exemplary Programs

We identified many more activities than projects or whole courses, yet many more of the projects and courses met our pedagogical criteria than did the activities. Activities, while often incorporating some aspects of inquiry, require teachers to build a curriculum around them to ensure that they can be used for inquiry. In contrast, we selected projects and whole curricula that embed inquiry into the program. As a result, we have selected only those activities that teachers can easily integrate into a course of study focused on inquiry. In some cases, the evidence for the effectiveness of these activities has come from testimonials, raising the concern that special professional development might be required for those seeking to achieve similar outcomes. Some of the activities we reviewed are designed for school as well as home use. In these cases, while the activities have the potential for fostering inquiry learning, they need to be integrated into a powerful inquiry program, without which their potential could be lost.

**1. Comprehensive Courses**

Several groups have created complete courses for mathematics and science that take advantage of technology to promote inquiry-based understanding. Many more courses mention the option of using calculators or spreadsheets or other technology tools but fail to integrate these tools in a meaningful way. We selected comprehensive curricula that made effective and consistent use of technology.

This review category includes programs that provide all the written materials, technology, and supplies needed to support student activities and to involve students actively in a complete, full-length mathematics or science course.

Traditional curricula often neglect authentic inquiry. Textbooks, in particular, have neither fostered questioning from students nor encouraged sustained problem solving (Schmidt, McKnight, & Raizen, 1997). Most texts offer concise explanations, examples drawn from straightforward, often artificial contexts, and opportunities to solve set problems.

Creators of comprehensive courses that incorporate technology need to redesign the curriculum to reflect the strengths and limitations of mathematical software. Students have less need to learn the mechanics of solving problems and therefore can spend more time on the complexities of designing solutions.

Designers of comprehensive courses that incorporate technology also have the opportunity to offer students feedback on their solutions. Many aspects of mathematical or scientific problem solving, such as setting up equations or labeling diagrams, lend themselves to computer-generated feedback.

The programs in the table below offer varying levels of support for teachers and diverse approaches to curriculum. In addition, all make use of technology to some extent. Programs, like Virtual High School, extend the traditional curriculum, providing opportunities for teachers and students to participate in courses not offered at their own school.

Comprehensive courses fit in the complex category of the enGauge framework. In addition, activities range from medium to high, depending on the choice of problems, for authenticity and constructivism.

We identified 15 courses that met our mandatory criteria and four that we deemed exemplary. The projects in this category appear in the chart below. Links to reviews of the exemplary projects are provided.

| Comprehensive Courses Reviewed | |
|---|---|
| Project/Review Link | URL |
| Comprehensive School Mathematics Program | http://198.17.205.11/csmp/ |
| Connected Mathematics * Exemplary * | http://www.math.msu.edu/cmp |
| Everyday Mathematics | http://everydaymath.uchicago.edu/ |
| FOSS | http://www.lhs.berkeley.edu/FOSS/FOSS.html |
| | |

| | |
|---|---|
| Growing with Mathematics | http://www.mimosausa.com/PRODUCT/GWMT.HTM |
| I Can Learn | http://www.icanlearn.com/ |
| Investigations<br>* Exemplary * | http://www.terc.edu/investigations/index.html |
| Math Trailblazers | http://www.math.uic.edu/IMSE/MTB/mtb.html |
| Mathematics in Context | http://www.ebmic.com/ebec/index.htm |
| Mathland | http://www.creativepublications.com/products/mathland/mathland.html |
| MMAP: Middle School Math through Applications Project<br>* Exemplary * | http://mmap.wested.org |
| Number Power | http://www.devstu.org/materials.html |
| Prime Science | http://www.teleport.com/~cgrether/resource/curriculum/prime1.html |
| SEPUP<br>* Exemplary * | http://www.lhs.berkeley.edu/sepup |
| University of Chicago School Mathematics Project | http://social-sciences.uchicago.edu/ucsmp |

## 2. Project-Based Curricula and Collaborative Projects

Project-based materials implement the NRC goal of fluency with information technology as well as the mandatory and exemplary criteria of this report in the most complete way. Projects by their nature focus on a compelling, relevant question and require several iterations to be completed. In addition, developers have often incorporated powerful technologies first used by experts into these materials. Expert tools, when tailored to students, have great potential to encourage the same sort of inquiry we value in scientists. Projects also generally require groups of students to collaborate and provide multiple points of entry for diverse students. Among the projects meeting our mandatory criteria, we found variation in the uses of technology and in the authenticity of the problems.

Projects fit in the complex and constructivist category of the enGuage framework. In addition, activities range from medium to high, depending on the choice of problems, for authenticity.

We identified 16 project-based curricula that met our mandatory criteria and six that we deemed exemplary. The projects in this category appear in the chart below. Links to the exemplary project reviews is available below.

| Project-Based Curricula and Collaborative Projects Reviewed | |
|---|---|
| Projects/Review Link | URLs |
| Alive Math | http://hydra.educ.queensu.ca/maths/ |
| CIESE | http://www.k12science.org/currichome.html |
| GEMS | http://www.lhs.berkeley.edu/GEMS |
| Global Lab<br>* Exemplary * | http://globallab.terc.edu/home.html |
| GLOBE | http://www.globe.gov |
| IMMEX<br>* Exemplary * | http://www.immex.ucla.edu/ |

| | |
|---|---|
| Jasper Woodbury<br>* Exemplary * | http://peabody.vanderbilt.edu/projects/funded/jasper/ |
| Knowledge Forum | http://www.learn.motion.com/lim/kf/KF0.html |
| Math League | http://www.mathleague.com/ |
| MathMagic | http://forum.swarthmore.edu/mathmagic/ |
| Model-It<br>* Exemplary * | http://hi-ce.org/sciencelaboratory/modelit/index.html |
| One Sky Many Voices<br>* Exemplary * | http://www.onesky.umich.edu |
| Scientists in Action | http://peabody.vanderbilt.edu/projects/funded/sia/ |
| The Jason Project | http://www.jasonproject.org |
| Thinkertools | http://thinkertools.berkeley.edu:7019/simulate.html |
| Web-based Integrated Science Environment<br>* Exemplary * | http://wise.berkeley.edu/ |
| World Watcher | http://www.worldwatcher.nwu.edu/ |

### 3. Activities and Skill Acquisition

This category of projects includes perhaps the greatest number of titles and authors. Many high quality CD-ROM and kit-based activities have been designed for students at all grade levels and for all mathematics and science topics. Typically, these activities are self-contained, in the sense that they come with all the materials needed and require no supplemental software or curriculum in order to be used. Often, they are self-paced and self-guided activities that would be suitable for independent student work (e.g., from home or after school). There is a great diversity in this category, with some projects featuring elaborate projects that include hands-on activities, teacher-led discussions, and CD-ROM or Internet components. Others are quite simple, and may provide students only with a skills practice framework.

Typically, these activities come with all the materials needed and require no supplemental software such as a word processor or spreadsheet. Some are suited to self-paced and self-guided use (e.g., from home or after school). There is a great diversity in this category, even within the titles selected by organizations such as NCTM. Some projects feature collaboration, manipulative materials, and construction of artifacts. Others are quite simple, and may provide students only with a skills practice framework.

The success of these activities depends on teachers taking the initiative to emphasize inquiry. Unfortunately, even the projects we review here rarely meet our criteria for professional development. Generally, these projects consist of a high quality set of materials, very good intentions relating to student inquiry, and varying levels of support for students and teachers.

Activities and skill acquisition projects fit in the didactic category of the enGuage framework. In addition, activities range from low to medium, depending on the use in the classroom, for authenticity and complexity.

We identified thirty-nine activities that met our mandatory criteria, six of which were deemed exemplary, and one set of reviewed activities from the NCTM that was also judged to be exemplary. The projects in this category appear in the chart below. Links to reviews of exemplary projects are provided.

| **Activities and Skill Acquisition Projects Reviewed** | |
|---|---|
| Project/Review Link | URL |
| Artemis | http://hi-ce.org/sciencelaboratory/ |

| | |
|---|---|
| | artemis/index.html |
| Building Perspective * Exemplary * | http://www.sunburst.com/ |
| Cyberlearning CD Roms | http://www.cyberlearn.com |
| Evergreen Project | http://www.evergreenproject.com/ |
| Fizz and Martina | http://www.tomsnyder.com/ |
| Funbrain | http://www.funbrain.com |
| Gallery of Interactive Geometry | http://www.geom.umn.edu/apps/gallery.html |
| Graph Club | http://www.tomsnyder.com/ |
| Great Ocean Rescue | http://www.tomsnyder.com/ |
| Great Solar System Rescue | http://www.tomsnyder.com/ |
| Hands-on Universe | http://hou.lbl.gov/index.html |
| How the West Was One + Three x Four | http://www.sunburst .com/ |
| Inner Body Works | http://www.tomsnyder.com/ |
| Japanese Math Challenge | http://www.japanese-online.com/math/ |
| Logical Journey of the Zoombinis * Exemplary * | http://www.mattelinteractive.com/ |
| Math Arena | http://www.sunburst .com/ |
| Math Blaster Series | http://www.knowledgeadventure.com/home/ |
| Math for the Real World | http://www.knowledgeadventure.com/home/ |
| Math Munchers Deluxe | http://www.learningcompanyschool.com/school/products/mmd.htm |
| Math Mysteries | http://www.tomsnyder.com/ |
| Millie's Math House * Exemplary * | http://www.edmark.com/ |
| Mindtwister Math | http://www.edmark.com/ |
| NCTM e-Examples * Exemplary * | http://standards.nctm.org/document/eexamples/ |
| Ocean Expeditions | http://www.tomsnyder.com/ |
| Prime Time Math | http://www.tomsnyder.com/ |
| Reader Rabbit Math Series | http://www.learningcompanyschool.com/ |
| Riverdeep Interactive Learning | http://www.riverdeep.net |
| Sammy's Science House | http://www.edmark.com/ |
| Science Court * Exemplary * | http://www.tomsnyder.com/ |
| Science Seekers | http://www.tomsnyder.com/ |
| SCORE | http://www.score.k12.ca.us |
| Sim Series | http://www.ea.com/tech_support/game_search.cfm |
| Space Academy | http://www.tomsnyder.com/ |
| Tenth Planet | http://www.tenthplanet.com/ |
| The Factory * Exemplary * | http://www.sunburst.com/ |

| | |
|---|---|
| Thinkin' Things all around FrippleTown * Exemplary * | http://www.edmark.com/ |
| Time Warp of Dr. Brain | http://www.sierra.com/ |
| WebQuests | http://edweb.sdsu.edu/webquest/webquest.html |
| Whyville | http://www.whyville.net |

## 4. Computational and Representational Tools

Computational and representational tools make it easy for students to perform "what if" experiments and to concentrate on the meaning of, for example, statistics. Learners typically manipulate objects in their simulations to test performance under different conditions. For example, with Geometer's Sketchpad, students can make a construction and test it by varying an angle or changing the size of an object. Technology projects in this category can help students manipulate algebraic expressions, compute statistics, or explore representations of mathematical objects. For example, students may explore graphs of $y = ax2$ for various values of a, or triangles with a given angle. Environments may also link different representations (e.g., functions and graphs, plane figures and their areas, or scatter plots and lines of best fit). These environments allow students to quickly examine a collection of cases-and to generate conjectures, which may then be justified with a mathematical argument, disproved, or investigated further.

Models can represent complex scientific situations like an ecosystem or the world of Newtonian physics. Students can manipulate models with a computer to make conjectures, test their ideas, and explore the rules underlying scientific phenomena. In addition to manipulating existing models, students can modify models or create their own models. For example, they might model a simple predator/prey relationship by defining the rate at which the predator species successfully hunts its prey and the rate at which both species reproduce. Running such a model on the computer simulates how the relative populations of the two species fluctuate over time.

Three research efforts relate to the potential impact of modeling activities in the science or mathematics classroom. The first is work on constructionist learning environments by researchers such as Resnick and Repenning (Repenning, Ioannidou, & Phillips, 1999; Resnick, Berg, & Eisenberg, 2000). Constructionism extends some of the ideas behind constructivist learning by placing students in environments in which they construct physical objects such as models. Resnick's work with StarLOGO, a parallel processing version of the LOGO graphical programming language, has some similarity to Creator in that students specified the behavior of individual agents, placed the agents within a world and observed what happened over time (Resnick, 1996). In his study, Resnick worked with small groups of students who were able to design dynamic systems that display complex behavior, such as traffic jams, even though the systems were based on very simple rules. Resnick's work established the promise of dynamic modeling environments like StarLOGO and Creator to allow students to learn about complex scientific ideas by modeling them.

The second effort is research by Clayton Lewis and his colleagues at the University of Colorado on the KidSim and AgentSheets software in elementary classrooms. The software engaged students in developing models of life science phenomena such as small ecosystems (trees, grasses, and rabbits, for example), and aspects of human health (such as the circulatory system).

The third effort is a report for the Educational Testing Service on the relationship of educational technology and student achievement in mathematics (Wenglinsky, 1998). The report draws on data from the 1996 National Assessment of Educational Progress to argue that certain uses of computers, including the use of simulations, were associated with improved academic performance and school climate. At the eighth grade level, the closest grade level to high school in the study, researchers found that using computers to teach higher order thinking skills was associated with an improvement in academic performance and school climate. This report raises the possibility that using model-building activities in the science or mathematics curriculum will engage students in higher order thinking and problem solving.

The environments described here were not developed with a particular curriculum in mind. Some are designed for students by professionals in mathematics or science. Others are designed to aid student learning in particular ways. In both cases, it is important to consider the mathematical understanding that the technology may foster with regard to existing curricula and mathematics standards. Some of the tools included here are also incorporated into comprehensive curricula or projects. Many center around a particular simulation or representational environment and address very specific content learning goals. In some cases, the developers of the technology believe strongly in providing such tools to teachers, who then integrate the use of the technology into their curriculum, as is the case for Kalidomania and Geometer's Sketchpad. In other cases, the developers provide a curriculum that puts the tool in context and supports the tool. Computational and representational tools fit in the complex category of the enGuage framework. In addition, activities designed by developers or teachers can range from medium to high, depending on the choice of problems, for authenticity and constructivism.

We identified 13 tools that met our mandatory criteria and five that we deemed exemplary. The projects in this category appear in the chart below. Links to reviews of the exemplary projects are provided.

| Computational and Representational Tools Reviewed | |
|---|---|
| Project/Review Link | URL |
| AgentSheets * Exemplary * | http://www.agentsheets.com |
| Concord Probes | http://www.concord.org/probesight/ |
| Function Probe | http://questmsm.home.texas.net/Products/FProbe/FPWelcome.html |
| Geometer's Sketchpad * Exemplary * | http://www.keypress.com/catalog/products/software/Prod_GSP.html |
| Imagiworks Software | http://www.imagiworks.com |
| Kaleidomania | http://www.keypress.com/catalog/products/software/ Prod_KaleidoMania.html |
| Pasco Passport | http://www.pasco.com |
| Programmable Brick | http://el.www.media.mit.edu/groups/el/projects/programmable-brick/more.html |
| SimCalc * Exemplary * | http://tango.mth.umassd.edu/ |
| Stagecast Creator * Exemplary * | http://www.stagecast.com/ |
| StarLogo * Exemplary * | http://el.www.media.mit.edu/groups/logo-foundation/index.html |
| Symphony | http://www.hi-ce.org/sciencelaboratory/symphony/index.html |
| Vernier | http://www.vernier.com/ |

## 5. Resource Web Sites (links to reviewed sites and online resources)

As innovative uses of technology to support mathematics learning proliferate, groups are beginning to review, select, and promote promising activities, projects, software, and units much as groups have rated filmstrips in the past. While these projects do not necessarily make strong use of technology in science or mathematics, they nevertheless make a significant contribution to education in these domains. In this category, we review Web sites that are carefully monitored, provide access to accurate information, and offer useful resources, such as problems of the week.

Resource Web sites do not fit into a single place in the enGuage framework. Instead they range along all dimensions and can vary dramatically depending on teacher usage. The Web resources most likely to meet our criteria will be above average on the dimensions of complexity, authenticity, and constructivism.

We identified three resource Web sites that met our mandatory criteria and two that we deemed exemplary. The projects in this category appear in the chart below. Links to reviews of the exemplary projects provided.

| Resource Web Sites Reviewed | |
|---|---|
| Project/Review Link | URL |
| Math Forum * Exemplary * | http://forum.swarthmore.edu/ |
| NCTM Web Resources * Exemplary * | http://illuminations.nctm.org/webresources/index.html |
| PBS Teacher Source | http://www.pbs.org/teachersource/math/ middle_analysis.shtm |

### IV. Next steps

The programs we have reviewed represent first steps toward effective incorporation of technology into the curriculum. The research supporting them is similarly preliminary. A vigorous, intellectually rich, and mutually supportive set of research programs is essential to continue to improve the science and mathematics curriculum. We need research studies that investigate how programs evolve in classroom settings and that incorporate lessons learned from these investigations. We need to ensure that research findings are communicated widely and that the results are reported such that they benefit other investigators. Too often reports are so abstract that readers cannot imagine the characteristics of the learning environment.

To support a process of continuous improvement, we need professional development opportunities that allow groups to test and revise materials jointly¾customizing them to local conditions. Some projects are very conscious of professional development: they suggest implementation plans that involve all the stakeholders in a district and include plans for having experienced teachers help others. Good examples are found in Connected Math and TERC's Investigations.

We also need support for curriculum materials development projects that allow time for testing, review, and revision. Several of the NSF-funded projects selected as exemplary have benefited from this kind of support. This point is made clearly by Schoenfeld in *Looking Toward the 21st Century: Challenges of Educational Theory and Practice* (October 1999, p. 11):

> *We must recognize that the kinds of combined research and development efforts suggested here will require significant amounts of time and money—and that to date we have not been willing to make such investments as a nation. Early attempts, such as the science and mathematics curriculum projects initiated following the Soviet Union's successful launching of Sputnik, tended not to involve the educational research community. More recent attempts have done so, but they have not been of adequate scale. For example, I applaud the National Science Foundation for taking the initiative, earlier in this decade, to fund some major curriculum projects. Some of those projects had solid connections with the research community. But—and this is not a criticism of NSF, but of the constraints that shaped the approach they took—it doesn't take a very close look to realize that the conditions under which the curriculum developers were compelled to work were next-to-impossible. One project, for example, had a five-year grant to develop five years' worth of curriculum. Six months into the project, the project leader said she felt that she was already very far behind schedule! That kind of compressed time scale allows time for little more than the following four-step development cycle:*
>
> - *Write instructional materials on the basis of what you know*
> - *Field test the materials you've written*

- *Revise once on the basis of what you've seen*
- *Pray. That just won't do.*

*We have to make a long-term investment in building instructional materials, and learning from what we do as we do it.*

## V. References

Ainsworth, S. E., Bibby, P. A., & Wood, D. J. (1998). Analysing the costs and benefits of multi-representational learning environments. In M. W. Van Someren and P. Reimann (Eds.), *Learning with multiple representations*. Oxford: Elsevier Science.

American Association for the Advancement of Science (1993). *Benchmarks for science literacy: Project 2061*. New York: Oxford University Press.

AAUW Educational Foundation Commission on Technology, Gender, and Teacher Education. (2000). *Tech-savvy: Educating girls in the new computer age*. Washington, DC: American Association of University Women.

AAUW Educational Foundation. (1998). *Gender gaps: Where schools still fail our children*. Washington, DC: American Association of University Women.

Athens, M. & Cohn, G. (1999 January 31). It's in the book, and it's wrong; Errors: U.S. publishers routinely produce attractive textbooks that are shallow and riddled with factual mistakes. *Baltimore Sun*, 1A.

Baumgartner, E. & Reiser, B. J. (1998). *Merging engineering and scientific reasoning: High school students' use of scientific evidence in design projects*. San Diego, California.

Begel, A. (1998). *StarLogo*. Invited talk at Santa Fe Institute Workshop on GIS Systems and Modeling.

Begel, A. (1999). *StarLogo: Building a modeling construction kit for kids*. Invited talk at Agent Simulation: Applications, Models and Tools.

Berenfeld, B. (1994). Technology and the new model of science education: The Global Lab experience. *Machine-Mediated Learning, 4*(2/3), 203-227.

Boone, G. (1998). Task Force: Environmental investigation kit. *The American Biology Teacher, 60*(4).

Borko, H. & Putnam, R. (1996). Learning to teach. In D. Berliner & R. Calfee (Eds.), *Handbook of educational psychology* (pp. 673-708). New York: Macmillan.

Borst, R. (1997). Classroom air quality: Exploring the indoor environment. *Clearing 98*, 14-15.

Bos, N., Drabenstott, K., Krajcik, J., Soloway, E., Talley, M., Woolridge, S., & Miller, J. (2000). *Students' searching and evaluating with the Artemis Interface to a digital library*. International Conference on Learning Sciences. Ann Arbor, MI.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (Eds.). (1999). *How people learn: Brain, mind, experience, and school*. National Academy Press, Washington, DC.

Brown, M., & Edelson, D. C. (1999). A lab by any other name: Integrating traditional labs and computer supported collaborative science investigations. In C. Hoadley (Ed.), *Proceedings of Computer Supported Collaborative Learning 1999* (pp. 73-80). Palo Alto, CA.

Burrill, G. et al. (1999). *Exploring regression: Data-driven mathematics*. White Plains, NY: Dale Seymour Publications. [Reviewed in this document.]

Cognition and Technology Group at Vanderbilt (1990). Anchored instruction and its relationship to situated cognition. *Educational Researcher, 19*(6), 2-10.

Cognition and Technology Group at Vanderbilt. (1993). Anchored instruction and situated cognition revisited. *Educational Technology, 33*, 52 70.

Confrey, J. & Mahoney, A. (1996). Function probe. *Communications of the Association for Computing Machinery 39*(8), 86-87. Available at: http://www.acm.org/pubs/articles/journals/cacm/1996-39-8/p86-confrey/p86-confrey.pdf.

Cuoco, A., Goldenberg, P. E. & Mark, J. *Habits of mind: an organizing principle for mathematics curriculum*. Available at: http://www.edc.org/LTT/ConnGeo/HOM.html.

Edelson, D. C., Gordin, D. N., & Pea, R. D. (1999). Addressing the challenges of inquiry-based learning through technology and curriculum design. *Journal of the Learning Sciences, 8*(3/4), 391-450.

Fennema, E. & Leder, G. (Eds.). (1990). *Mathematics and gender*. Teachers College Press: New York.

Flowers, J. (1998). A study of proportional reasoning as it relates to the development of multiplication concepts. Doctoral dissertation, University of Michigan, Ann Arbor, MI.

Garcia, E. (1998). Salmon conflict. *The Science Teacher, 65*(2), 72.

Goodrow, A. M. (1998, May). Children's construction of number sense in traditional, constructivist, and mixed classrooms. Doctoral dissertation, Tufts University, Medford, MA.

Gordin, D. N., & Pea, R. D. (1995). Prospects for scientific visualization as an educational technology. *Journal of the Learning Sciences, 4*(3), 249-279.

Hedges, L., Stodolsky, S., Mathison, S., & Flores, P. (1986). *Transition Mathematics: Field Study.*

Hirschhorn, D. B. A longitudinal study of students completing four years of UCSMP mathematics. *Journal for Research in Mathematics Education, 24*, (1993): 136-158.

Hirshhorn, D., Senk, S. Thompson, D., & Usiskin, Z. (1995). Rethinking the first two years of high school mathematics with the UCSMP. *Mathematics Teacher, 88*(8).

Hsi, S., & Hoadley, C. M. (1997). Productive discussion in science: Gender equity through electronic discourse. *Journal of Science Education and Technology, 6*(1), 23-36.

Hyde, J. S., Fennema, E, Ryan, M., Frost, L., & Hoop, C. (1990). Gender comparisons of mathematics attitudes and affect: A meta-analysis. *Psychology of Women Quarterly, 14*, 299-324.

Jackson, S., Stratford, S., Krajcik, J., & Soloway, E. (1995). *Model-It: A case study of learner-centered software for supporting model building*. Paper presented at the Working Conference on Technology Applications in the Science Classroom, Columbus, OH.

Jackson, S., Stratford, S., Krajcik, J., & Soloway, E. (1996). Making dynamic modeling accessible to pre-college science students. *Interactive Learning Environments, 4*(3).

Kessel, C. & Linn, M.C. (1996). Grades or scores: Predicting future college mathematics performance. *Educational Measurement: Issues and Practice, 15* (4), 10-14, 38.

Koella, & Hofer. (in press). *StarLOGO for teachers.*

Koker, M. (1992a). *SEPUP in Cleveland: An impact study of SEPUP on teachers and students.* Berkeley, CA: Science Education for Public Understanding Program.

Koker, M. (1992b). *SEPUP in Philadelphia: An impact study of SEPUP on teachers and students.* Berkeley, CA: Science Education for Public Understanding Program.

Koker, M. (1996). *Students' decisions about environmental issues and problems: An evaluation study of the SEPUP program.* Unpublished Ph. D. Dissertation, University of Southhampton.

Koker, M., & Thier, H. (1994). *Learning about environmental health risks: An evaluation study of the SEPUP Investigating Environmental Health Risks module.* Berkeley, CA: Science Education for Public Understanding Program.

Krajcik, J., Blumenfeld, P. C., Marx, R. W., Bass, K. M., Fredricks, J., & Soloway, E. (1998). Inquiry in project-based science classrooms: Initial attempts by middle school students. *The Journal of the Learning Sciences, 7*(3&4), 313-350.

Krajcik, J., & Layman, J. (1993). Microcomputer-based laboratories in science classroom. *Research Matters o the Science Teacher, 31.*

Kulm, G. (1999, May). Evaluating mathematics textbooks. *Basic Education, 43*(9), 6-8. Available at: http://www.project2061.org/newsinfo/research/articles/cbe.htm

Lewis, C. C., & Tsuchida, I. (1998). A lesson is like a swiftly flowing river. *American Educator, 21*(3), 12, 14-17, 50-52.

Lichtenstein, G., Weissglass, J., & Ercikan-Alper, K. (1998). *Final evaluation report: Middle School Mathematics through Applications Project, MMAP II (1994-1998).* Denver, CO: Quality Evaluation Designs.

Linn, M. C. & Hsi, S. (2000). *Computers, teachers, peers: Science learning partners.* Mahwah, NJ: Lawrence Erlbaum Associates.

Ma, L. (1999). *Knowing and teaching elementary mathematics: Teachers' understanding of fundamental mathematics in China and the United States.* Mahwah, NJ: Lawrence Erlbaum Associates.

Martin, D. B. (2000). *Mathematics succes and failure among African-American youth.* Mahwah, NJ: Lawrence Erlbaum Associates.

Mathison, S., Hedges, L., Stodolsky, S., Flores, P., & Sarther, C. (1989). *Teaching and learning algebra: An evaluation of UCSMP Algebra.*

Means, B., Coleman, E., Lewis, A., Quellmalz, E., Marder, C., & Valdes, K. (1997). *GLOBE Year 2 Evaluation Findings.* Menlo Park, CA: SRI International.

Means, B., Coleman, E., Lewis, A., Quellmalz, E., & Valdes, K. (1996). *GLOBE Year 2 Evaluation Findings.* Menlo Park, CA: SRI International.

Mokros, J., Berle-Carman, M., Rubin, A., & O'Neil, K. (1996, April). *Learning* *operations: Invented strategies that work.* Paper presented at the annual meeting of the American Educational Research Association, New York, NY.

Mokros, J., Berle-Carman, M., Rubin, A., & Wright, T. (1994, December). Full year pilot grades 3 and 4: Investigations in number, data, and space. Cambridge, MA: TERC (available from the authors).

Mokros, J. R., & Tinker, R. F. (1987). The impact of micro-computer based labs on children's ability to interpret graphs. *Journal of Research in Science Teaching, 24*(4), 369-383.

Monaghan, J., Slotta, J. D., & Cuthbert, A. (1999). *A professional development model for effective Internet use: The Web-based Integrated Science Environment (WISE).* Paper presented at the Annual Meeting of the National Association for the Research in Science Teaching, Boston, MA.

National Council of Teachers of Mathematics. (1989). *Curriculum and evaluation standards for school mathematics.* Reston, VA: NCTM.

National Council of Teachers of Mathematics. (2000). *Principles and standards for school mathematics.* Reston, VA: Author.

National Institute on Student Achievement, Curriculum, and Assessment, Office of Educational Research and Improvement, U. S. Department of Education (1998). *The educational system in Japan: Case study findings.* Available at: http://www.ed.gov/pubs/JapanCaseStudy/index.html.

National Institute on Student Achievement, Curriculum, and Assessment, Office of Educational Research and Improvement, U. S. Department of Education (1999). *The Japanese education system: A case study summary and analysis.* Available at: http://www.ed.gov/pubs/ResearchToday/98-3038.html.

National Research Council (1996). *National science education standards.* http://books.nap.edu/html/nses/html/index.html

National Research Council. (1999). *Being fluent with information technology.* Washington, DC: National Academy Press.

National Science Foundation (NSF) (1997). *Report of expert panel materials review.*

Penrose, R. (1989). *The emperor's new mind: Concerning computers, minds, and the laws of physics.* Oxford: Oxford University Press.

Petrovic, C., & Lavity, H. (1998). Coral Kingdom. *Reef Encounter: Newsletter of the International Association for Reef Studies, 23.*

Piaget, J. (1929). *The child's conception of the world.* London: Routledge & Kegan Paul.

Report of expert panel on Technology: http://www.ed.gov/pubs/edtechprograms/theexpertpanel.html

Repenning, A., Ioanidou, A., & Phillips, J. (1999). Collaborative use and design of interactive simulations. In C. Hoadley (Ed.), *Proceedings of CSCL 1999.* Stanford, CA.

Resnick, M. (1991). MultiLogo: A study of children and concurrent programming. *Interactive Learning Environments, 1*(3), 153-170.

Resnick, M. (1994a). Changing the centralized mind. *Technology Review*, 32-40 (July).

Resnick, M. (1994b). Learning about life. *Artificial Life Journal, 1*(1-2), 229-241.

Resnick, M. (1994c). *Turtles, termites, and traffic jams: Explorations in massively parallel microworlds.* Cambridge, MA: MIT Press.

Resnick, M. (1995). New paradigms for computing, new paradigms for thinking. In . A. diSessa, C. Hoyles, & R. Noss (Eds.), *Computers and exploratory learning* (pp. 31-43). Berlin: Springer-Verlag.

Resnick, M. (1996). Beyond the centralized mindset. *Journal of the Learning Sciences, 5*(1), 1-22.

Resnick, M., Martin, F., Sargent, R., & Silverman, B. (1996). Programmable bricks: Toys to think with. *IBM Systems Journal, 35*(3-4), 443-452.

Rohlen, T. P., & LeTendre, G. K. (Eds.) (1996). *Teaching and learning in Japan.* Cambridge: Cambridge University Press.

Roseman, J.E., Kesidou, S., Stern, L., & Caldwell, A. (1999, November/December). Heavy books light on learning: AAAS Project 2061 evaluates middle grades science textbooks. *Science Books & Films, 35*(6), 243-247. Available at: http://www.project2061.org/newsinfo/research/textbook/articles/heavy.htm

Ruben, B, (1994). Cyber-Ed. *Envrionment Action, 26*(1), 24-27.

Sadker, M. & Sadker, D. (1994). Failing at fairness: How America's schools cheat girls. New York: Maxwell Macmillan International.

Samson, S., & Wilson, M. (1996). *The SEPUP Issues, Evidence and You curriculum: Achievement and student attitude evidence from the pilot year.* Paper presented at the Annual Conference of the American Educational Research Association, New York.

Sargent, R. (1995). *The programmable LEGO brick: Ubiquitous computing for kids.* Master's Thesis, MIT Media Laboratory.

Sargent, R., Resnick, M., Martin, F., & Silverman, B. (1995). Building and learning with programmable bricks. In *Logo Update, Volume 3*, Number 3. Available from the Logo Foundation, 250 West 57th Street, New York, NY 10107-2228; (212) 765-4918.

Sargent, R., Resnick, M., Martin, F., & Silverman, B. (1996). Building and learning with programmable bricks. In Y. Kafai & M. Resnick (Eds.), *Constructionism in practice: Designing, thinking, and learning in a digital world.* Mahwah, NJ: Lawrence Erlbaum Associates.

Schmidt, W. H., McKnight, C. C., & Raizen, S. (1997). *A splintered vision: An investigation of U.S. science and mathematics education.* Boston: Kluwer.

Schmidt, W. H., McKnight, C. C., Cogan, L. C., Jakwerth, P. M. & Houang, R. T. (1999). *Facing the consequences: Using TIMSS for a closer look at U.S. mathematics and science education.* Boston: Kluwer.

Schoenfeld, A. H. (1999). Looking toward the 21st century: Challenges of educational theory and practice. *Educational Researcher, 28*(7), 4-14. Available at http://www.aera.net/pubs/er/arts/28-07/schoen01.htm.

Schwartz, D. L., Lin, X. D., Brophy, S., & Bransford, J.D. (In press). Toward the development of flexibly adaptive instructional designs. In C. Reigeluth (Ed.), *Instructional design theories and models: Volume II.* Mahwah, NJ: Lawrence Erlbaum Associates.

Schwartz, J., Yerushalmy, M., et al. (Eds.). (1993). The Geometric Supposer: What is it a case of? *Technology in Education*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Seymour, E. & Hewitt, N. (1994). *Talking about leaving: Factors contributing to high attrition rates among science, mathematics and engineering majors undergraduate majors*. Final report to the Alfred P. Sloan Foundation on an ethnographic inquiry at seven institutions.

Sherwood, R., Petrosino, A., Lin, X. D., & the Cognition and Technology Group at Vanderbilt (1998). Problem based macro contexts in science instruction: Design issues and applications. In B. J. Fraser & K. Tobin (Eds.), *International handbook of science education* (pp. 349-362). Dordrecht, Netherlands: Kluwer.

Slotta, J. D. & Linn, M. C. (2000). How do students make sense of Internet resources in the science classroom? In M.J. Jacobson & R. Kozma (Ed.), *Learning the sciences of the 21st century*. Mahwah, NJ: Lawrence Erlbaum Associates.

Stevenson, Harold & Stigler, James (1992). *The learning gap: Why our schools are failing and what we can learn from Japanese and Chinese education*. New York: Simon and Schuster.

Stigler, J. W., & Hiebert, J. (1999). *The teaching gap: Best ideas from the world's best teachers for improving education in the classroom*. New York: Free Press.

Stigler, J. W., Lee, S., and Stevenson, H. W. (1990). *Mathematical knowledge of Japanese, Chinese, and American elementary school children*. Reston, VA: National Council of Teachers of Science and mathematics.

Stratford, S. (1996). *Investigating processes and products of secondary science students using dynamic modeling software*. Unpublished Doctoral Dissertation, University of Michigan.

Spitulnik, M.W. (1998). *Construction of technological artifacts and teaching strategies to promote flexible scientific understanding*. Unpublished Doctoral Dissertation, University of Michigan.

Thompson, D. (1993). *An evaluation of a new course in precalculus and discrete mathematics*. Ph.D. Dissertation, University of Chicago, 1992. Abstracted in Dissertation Abstracts International, 54A (1993): 1716. Available from University Microfilms, Ann Arbor, MI.

U.S. Department of Education. National Center for Education Statistics. (1999). *The TIMSS videotape classroom study: Methods and findings from an exploratory research project on eighth-grade mathematics instruction in Germany, Japan, and the United States*, NCES 99-074, by Stigler, J.W., Gonzales, P., Kawanka, T., Knoll, S. & Serrano, A. Washington, DC: U.S. Government Printing Office.

Vye, N. J., Schwartz, D. L., Bransford, J. D., Barron, B. J., Zech, L., & Cognition and Technology Group at Vanderbilt (1998). SMART environments that support monitoring, reflection, and revision. In D. Hacker, J. Dunlosky, and A. C. Graesser (Eds.), *Metacognition in educational theory and practice* (pp. 305-346). Mahwah, NJ: Erlbaum.

Vygotsky, L. S. (1978). Mind in society: The development of higher psychological processes. Cambridge, Harvard University Press.

Wallace, R., & Kupperman, J. (1997). *On-line search in the science classroom: Benefits and possibilities*. Paper presented at the AERA, Chicago.

Washburn, D. K., & Crowe, D. W. (1988). *Symmetries of culture: Theory and practice of plane pattern analysis*. Seattle, WA: University of Washington Press.

Wenglinsky, H. (1998). *Does it compute? The relationship between educational technology and student achievement in mathematics* . Princeton, NJ: Educational Testing Service.

WestEd, (1998). *July 1998 IMMEX Training Institute evaluation summary.*

White, B. (1993). Thinkertools: Causal models, conceptual change, and science education. *Cognition and Instruction, 10*(1), 1-100.

Williams, L. M. (2000). *Exploring how a web-based integrated science environment and hands-on science can promote knowledge integration.* Poster session presented at the annual meeting of the American Education Research Association, New Orleans, LA.

Yoshida, M. (1999). *Lesson study: A case study of a Japanese approach to improving instruction through school-based teacher development.* Unpublished Ph.D. dissertation, University of Chicago.

Young, V. M., Haertel, G., Ringstaff, C., & Means, B. (1998). *Evaluating Global Lab curriculum: Impacts and issues of implementing a project-based science curriculum.* Menlo Park, CA: SRI International.

Return to Resources database

# NOTICE

# Reproduction Basis

| | |
|---|---|
| X | This document is covered by a signed "Reproduction Release (Blanket)" form (on file within the ERIC system), encompassing all or classes of documents from its source organization and, therefore, does not require a "Specific Document" Release form. |
| | This document is Federally-funded, or carries its own permission to reproduce, or is otherwise in the public domain and, therefore, may be reproduced by ERIC without a signed Reproduction Release form (either "Specific Document" or "Blanket"). |