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ABSTRACT

This document is intended as a resource and guide to help teachers integrate a problem-centered approach into their curricula. It outlines the typical components of problem-centered mathematics and science activities, and offers practical suggestions, examples, and resources to assist this endeavor. The first section of this document, "What is Problem-Centered Learning?", discusses how problem-centered learning is different from traditional methods of instruction, what problem-centered learning can do for students, and practical concerns from teachers. Section II, "How Can You Implement Problem-Centered Learning in Your Classroom?", discusses posing appropriate questions, working in small groups, sharing as a whole class, and assessing student learning. The third section includes descriptions of resource materials-mathematics and science education programs, resource books and catalogs, textbooks and activity books, other publications, and human resources. Scattered throughout the document are sections entitled "Dynamite Ideas" that highlight exemplary, problem-centered learning programs from across the United States. This publication also discusses research details the need for and benefits of problem-centered learning. Questions that can be used to determine the learning styles of a class of students are appended. (40 references) (KR)

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HOT TOPICS:
USABLE RESEARCH

PROBLEM-CENTERED LEARNING IN MATHEMATICS AND SCIENCE

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HOT TOPICS:

Usable Research

PROBLEM-CENTERED LEARNING IN MATHEMATICS AND SCIENCE

by Stephanie Kadel

February 1992

SERVE

SouthEastern Regional Vision for Education

Affiliated with

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- serve as a broker of exemplary research and practice, and
- become an invaluable source of information for individuals working to promote systemic educational improvement.

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HOT TOPICS: PROBLEM-CENTERED LEARNING IN MATHEMATICS AND SCIENCE was developed with the help of a Regional Review Panel consisting of State Department of Education representatives from each of the SERVE states. These educators were brought together at a SERVE Mathematics, Science, and Technology Forum during which this *Hot Topics* publication was reviewed and discussed.

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Hot Topics: Problem-Centered Learning in Mathematics and Science

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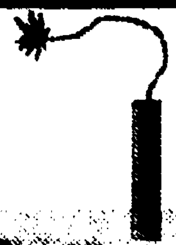

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INTRODUCTION

The primary purpose of educational reform is to improve the quality of teaching and learning in classrooms. The need for reform is especially urgent in mathematics and science because we must better prepare students to live and work in a rapidly changing, technological society. A recent survey of managers of one of this region's largest high-tech employers concluded that this company's greatest demand was for people who can work in teams to solve problems. The focus of problem-centered learning is to encourage and enable students to work together to examine problems which may have multiple or open-ended solutions—problems similar to those that students will face throughout their lives. While recognizing that this strategy could be used to teach individual students, small groups, or whole classes, this publication focuses on the research-endorsed method of problem-centered learning which uses small-group exploration and whole-class discussion to teach students new concepts and problem-solving skills.

Problem-Centered Learning in Mathematics and Science is intended as a resource and guide to help teachers integrate a problem-centered approach into their curricula. It outlines the typical components of problem-centered mathematics and science activities, and offers practical suggestions, examples, and resources to assist this endeavor. "Dynamite Ideas" highlight exemplary, problem-centered learning programs from across the nation. The teachers who practice this approach believe that they are teaching more effectively and that their students are learning more. This *Hot Topics* publication also discusses research which details the need for and benefits of problem-centered learning.

This document can be used by teachers, curriculum specialists, professional development coordinators, administrators, and teacher educators in implementing problem-centered learning and encouraging others to practice it. Teachers should find the implementation suggestions and lesson examples useful in changing their approach to teaching mathematics and science. Those who plan staff development and inservice activities may use information in this *Hot Topics* to design workshops on problem-centered learning. Teacher educators could include this publication in suggested reading materials on mathematics or science teaching strategies. And administrators and others can use the information in this document to plan school- or system-wide improvements in the way mathematics and science are taught.

Research findings from psychology indicate that traditional methods of teaching—which view the student as a passive absorber of information who "learns" material through repeated practice and reinforcement—are not satisfactory for most contexts (Resnick, 1987). Low scores on standardized tests seem to suggest that students at all levels are unable to make sense of number problems, though they have supposedly practiced and solved hundreds of them prior to tests ("Math Skills," 1991). Furthermore, scores on standardized science tests suggest that students are not making sense of science concepts or problem-solving strategies (Carnegie Foundation, 1983). The National Assessment of Educational Progress' (NAEP) report card on education in the nation found that one-third of eighth graders cannot solve problems that have more than one step, and half of all twelfth graders "appear to have an understanding of mathematics that does not extend much beyond simple problem solving with whole numbers" (Mullis, Dossey, Owen, & Phillips, 1991, pp. 7-8). These data cannot be ignored; traditional methods of teaching mathematics and science are failing to teach most students how to solve problems even though they will need this skill in order to function effectively in society.

Robert Gagne (1980)—a long-time proponent of problem-solving instruction—believes that the "central point of education is to teach people to think . . . to become better problem solvers," and emphasizes that research on cognitive processes indicates that thinking and problem solving can be taught. Gagne concludes, "If that is so, why are we not doing it?" (1980, p. 85). Many teachers *are* teaching their students to think and solve problems, but *all* teachers can benefit from enriching their instruction with a problem-centered perspective. Problem-centered learning will provide teachers with a means of teaching their students to think, because it insists upon active participation by students which will help them to learn and understand concepts in mathematics and science.

The push is clearly on for improved achievement in mathematics and science. These subjects were recognized as so significant that they became the focus of one of our national goals. Teachers will be expected to revise their approaches to teaching these subjects. Fortunately, the methods involved in a problem-centered learning activity are not new to most mathematics and science teachers; teachers have long used methods such as hands-on learning, problem solving, cooperative learning, and peer teaching, all of which are components of problem-centered learning. Furthermore, problem-centered learning is easy for teachers to use; it involves skills that most teachers have developed, such as asking open-ended questions, managing small groups, and facilitating discussions. Problem-centered learning combines these methods and teaching skills into a construct for teaching mathematics and science.

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A Sample Lesson

Title: Levers

Objective: To introduce levers as a kind of machine.

Aim: To have students discover how levers work and can be used.

Materials: empty paint cans, screwdriver, board with nails in it, crowbar, unopened juice bottles, bottle opener, brick, board, pile of books

Activities/Procedure:

- Introduce a lever by explaining only that it is a kind of machine.
- Divide students into four groups (or more if you have more materials).
- Group 1: Students will try to open paint cans with a screw driver.
- Group 2: Students will try to remove nails from a board using a crowbar.
- Group 3: Students will try to open juice bottles using a bottle opener.
- Group 4: Students will try to lift a pile of books using a brick and board.
- Provide brief directions to each group, but do not tell them how to accomplish the task.
- After a short time, reconvene the whole class.
- Allow students to discuss their group experiences with the class.
- Encourage students to formulate a working definition of a lever.

The following text describes this lesson as it might take place:
Ms. Johnson's third grade class was studying machines. The children had already discussed the purpose of machines and had decided that machines help people do work. The lesson for this day was on a simple machine, the lever. Ms. Johnson introduced the term "lever" and explained to the children that a lever was a kind of machine. She told them nothing more, but assigned groups of three or four students each to activity centers in the room. Each center required that students perform a task, such as remove nails from a board using a crowbar, open paint cans using a screwdriver, open juice bottles using a standard bottle opener, or lift a pile of books using a brick and a board.

Although some of the students were familiar with the various tools, many were not. The group working with the screwdrivers and paint cans began by trying to pound the screwdriver through the lids. Then one student remembered having seen his father open a

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can of paint by prying up the lid. Once the students figured out under which rim to place the screwdriver, they opened all of the cans on the table in short order. The students with the crowbar and nails had greater difficulty. None of the students in this group was familiar with the tool. They tried hooking the curved end under the nail, standing on the board and pulling up, but when even the strongest student in the group was unsuccessful they were moved to attempt a new strategy. Through trial and error, the group eventually discovered how to hook the crowbar under the nail and push down on the other end of the crowbar to remove the nail.

Similarly, the other groups tried various methods until each task had been completed successfully. Ms. Johnson then reconvened the students for a whole-class discussion. Each group chose one representative to describe the experiences of that group. Ms. Johnson prompted the class to discuss the similarities of the various methods and suggest what they thought a lever was. The children negotiated the meaning of each other's explanation and related it to their own observations. Ms. Johnson accepted each child's contribution. By the end of the period most of the children were able to explain in their own words a simple rule for how a lever works.

Throughout this activity and the activities that followed on other days, Ms. Johnson avoided giving children a definition of a lever, yet they had a good, "working" understanding of what a lever was and how it worked.

This example illustrates most of the components of a typical problem-centered activity, and will help define problem-centered learning more clearly; information on how to design problem-centered lessons is presented in Section II. While this example takes place in an elementary classroom, the components of problem-centered learning which are demonstrated in this scenario are applicable at all grade levels.

Problem-centered learning relies upon small-group interaction and whole-class negotiation to explore and develop solutions to problems. Problem-centered learning is especially relevant to mathematics and science teaching because it promotes the development of problem-solving skills through exploration and discovery. In many situations individuals approach a new task with prior knowledge; as they assimilate new information with what they already know, they actively make sense of experiences in their own way. Problem-centered learning encourages students to use this process when they are starting to learn new material, or when they are looking for answers to their own questions about how the world works.

Most students enter school with an endless list of questions about the world around them; they are natural scientists. The kinds of questions that students ask every day provide clues about what they think is interesting and important. Problem-centered learning allows teachers to use this information to design lessons which will help students find answers to some of their questions.

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DYNAMITE IDEA - Responding to Students' Concerns

At University Place Elementary in Tuscaloosa, Alabama, Susan Smith's mixed-grade, at-risk students are encouraged to explore questions that interest them. For example, one morning students discovered that some baby squirrels had fallen out of a nest; the students were worried about the squirrels and thought that the mother squirrel should have built a better nest. Ms. Smith challenged the students to try to build nests that would better hold baby squirrels. Teams of students were expected to work on this project outside and to be able to pick up their completed nests and show them to the other groups. The students soon found that certain materials did not work very well, and that it was not easy to build a stable nest which they could pick up. One group arranged materials on top of a large piece of bark, while another group used a cement block. For a follow-up activity, the class went to the library to find books about squirrels and nest building.

CONTACT INFORMATION: University Place Elementary School, 221 18th Street, Tuscaloosa (Tuscaloosa City Schools), AL 35401; (205) 759-3664

How Is Problem-Centered Learning Different from Traditional Methods of Instruction?

When mathematics and science teachers speak of their goals for student learning, they often emphasize the importance of helping students develop problem-solving skills. Indeed, this goal has been long-standing among science and mathematics educators and scholars (National Council of Supervisors of Mathematics, 1977; National Research Council, 1989; Champagne, Lovitts, & Calinger, 1990; Loucks-Horsley et al., 1990). In 1989, the National Council of Teachers of Mathematics specified curriculum standards for school mathematics in which the use of "problem-solving approaches to investigate and understand mathematical content" is identified as essential in teaching students to become productive citizens (p. 23). In addition, *Project 2061: Science for All Americans* (American Association for the Advancement of Science, 1989) asserts that young people learn best through hands-on, problem-centered activities.

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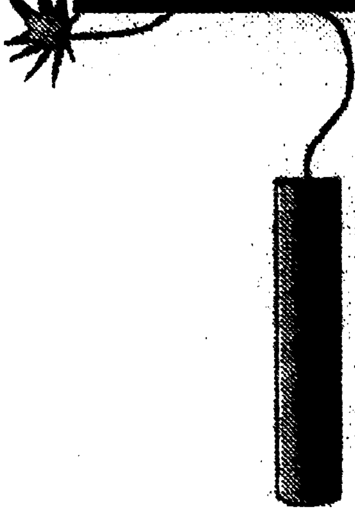
With the 1991 NAEP results revealing that many students can solve only the simplest math and science problems (Mullis, Dossey, Owen, & Phillips, 1991), it seems clear that existing mathematics and science teaching methods are not meeting expectations. Problem-centered learning gives students a process and framework for problem solving, while introducing concepts and theories.

DYNAMITE IDEA - Problem Solving Improves Test Scores



In 1980, Marion, Indiana implemented a new mathematics program which emphasized problem-centered learning in the elementary grades. Students were taught strategies for solving problems, including "look for a pattern," "guess and test," and "draw a diagram." Students solved sets of problems in small groups and then discussed their strategies and solutions in larger groups. After three years of implementation, which involved extensive teacher training and preparation, Marion Schools saw dramatic increases in students' standardized test scores. Scores for mathematics achievement on the Iowa Test of Basic Skills went from the 43rd percentile to the 73rd percentile in grade 5 and from the 18th percentile to the 74th percentile in grade two. Similar gains were reported in the other grades.
SOURCE: Wheatley, 1984

Several components of problem-centered learning differentiate it from traditional methods. A problem-centered learning approach teaches students three important learning skills:

A. to discover concepts and solve problems—instead of simply reading facts and then answering textbook questions or completing workbook exercises,
B. to think—not just to memorize, and
C. to cooperate in small groups—not to compete against each other.

A. Teaching Students to Solve Problems

To state that schools need to prepare students to solve problems seems obvious, yet, in the traditional mathematics or science classroom, meaningful and transferable problem-solving instruction rarely takes place. The textbook remains the primary teaching resource, but most textbooks presently in use actually serve as barriers to teaching effective problem solving. On a first examination of typical science and mathematics textbooks, it appears that students are practicing problem-solving skills with every assignment. Such textbooks seem to be filled with "problems" for students to solve; in most mathematics texts one finds page after page of number and word problems, and science textbooks present students with problems to which concepts must be applied to obtain a solution. However, many of these "problems" could more accurately be termed exercises; most are assigned after a period of rule-oriented instruction, and merely require students to identify and apply a prescribed procedure in order to reach a single solution. In nearly all cases students learn that there is generally only one right answer and one specified, correct way to obtain it. If students cannot remember and apply the rule or algorithm, they cannot solve the problem.

To be sure, direct instruction and rote learning are inseparable components of mathematics and science education. In order to advance to higher levels of thinking and problem solving, basic concepts and ideas must be explained, learned, and remembered. For example, students will not succeed in algebra if they have not memorized basic axioms such as the "R-S-T" (reflexive, symmetric, and transitive) properties. However, most concepts and ideas that should be learned in mathematics and science may be more interesting, more easily applied, and better remembered if they have been learned through exploration and discovery. When a problem-centered approach to learning mathematics and science is used, students who "forget" how to do a problem are able to regenerate an appropriate set of steps to obtain a solution.

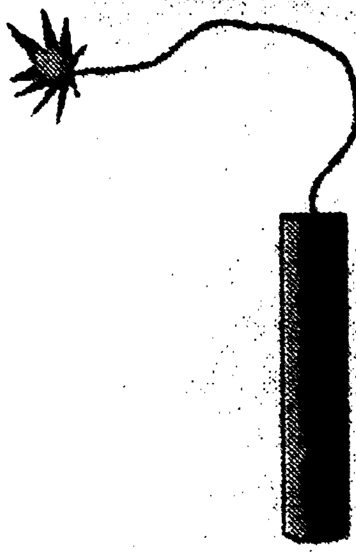
DYNAMITE IDEA - South Carolina's Learning Cycle

In 1990, the South Carolina Department of Education published a document entitled BSAP Science: Teaching Through Inquiry which encourages teachers to involve "students actively in problem solving and higher order thinking." This approach, which they call the "Learning Cycle," involves three phases. During the exploration phase, students work in groups and use hands-on experiences to investigate new concepts. During the concept development phase, students share their experiences with each other, look for patterns, and listen to explanations from the teacher. During the concept application phase, students attack a new problem using the information that they have learned during the previous phases. The teacher is encouraged to use activities in this last phase to begin exploration of new concepts; thus the cycle continues. The Learning Cycle is being used successfully in classrooms throughout South Carolina to design and teach lessons in science.
CONTACT INFORMATION: Lynn T. Altman, Science Consultant
South Carolina Department of Education, Columbia, SC 29201
(803) 734-8390.

B. Teaching Students to Think

Students who participate in problem-centered activities in school are learning to develop and apply thinking skills because they are expected to utilize their own resources and experiences when approaching new situations. Beyer (1987) asserts that teaching students to think helps them to do better academically and stay in school. When students understand the skills they need to "puzzle out" new concepts and accomplish tasks in the classroom, they achieve more and develop greater self-confidence about their ability to succeed. Learning to think is especially important in this information age because, as Beyer (1987) points out, "Exclusive reliance on past information and knowledge derived from it appears to be increasingly shaky as a basis for dealing with the fast changing . . . [world] in which we live" (p. 4). However, if students have learned how to think and reason, they will be better able to process new information and ideas. Problem-centered learning also helps students become task-oriented rather than performance-oriented, because it demonstrates that learning can be fun and teaches concepts and skills which students can apply to situations outside of school (Atkinson, 1958; Nicholls, 1983).

DYNAMITE IDEA - Thinking to Solve Problems

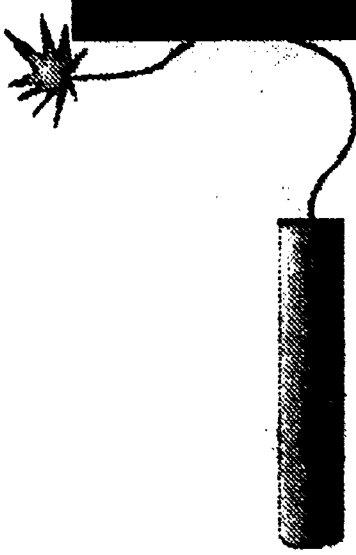


When teaching statistics and probability to eleventh and twelfth graders at the Mississippi School for Mathematics and Science in Columbus, Linda Bridges uses problems which will interest her students and make them think. For example, before explaining the laws of probability to them, she told groups of students that their team was playing a basketball game; the score was tied at the end-of-game buzzer, but one player had two free-throw shots. Students were asked, "If this player successfully completes foul shots 75 percent of the time, what is your team's chance of winning the game?" Because many of the students had already pondered this kind of problem as sports players or spectators, they were interested enough to want to solve it and used spinners, computations, and reasoning skills to do so. It also gave students an introduction to probability which Ms. Bridges could follow with class discussion and instruction.
CONTACT INFORMATION: Mississippi School for Mathematics and Science, P.O. Box W1627, Columbus, MS 39701; (601) 329-7360

C. Teaching Students to Cooperate

Students and teachers in a problem-centered classroom are cooperative partners in the process of exploration and discovery. Students are not worried about "doing it wrong," and look to the teacher and other students for new ideas, not evaluation. Students do not interrupt one another and suspend judgement of each others' ideas during discussion (Kamii & Lewis, 1990). They are involved in "information processing, rather than only information telling or receiving" (Beyer, 1987, p. 67). Teachers' roles and behaviors change as well. Teachers are willing to discuss questions to which no definite answers may be available. Teachers offer alternatives that invite students to investigate further or elaborate on ideas. Teachers (and their students) are willing to submit textbooks, other resources, and their own views to critical examination (Beyer, 1987).

DYNAMITE IDEA - Cooperating to Solve Problems



Helping students cooperate, develop thinking skills, and improve self-confidence are the goals of one elementary mathematics teacher at Village Oaks Elementary in Immokalee, Florida. Florence DiStefano (along with other teachers in her school) was given an introduction to problem-centered learning approaches by staff at the University of Miami, and now uses problem solving and student groups to teach new mathematics ideas. She focuses heavily on the development of thinking skills so that "children [can] approach a task without prior set-up," and uses thinking puzzles and manipulatives regularly. Learning to cooperate is encouraged by grouping students who Ms. DiStefano believes "don't communicate well together." For example, she once put her four usually uncooperative group members together for a problem-solving activity where they were to design a pattern. They found the solution before any other group. Ms. DiStefano believes that when these students were unable to step back and rely on someone else, they discovered not only a solution, but abilities that surprised themselves.

CONTACT INFORMATION: Village Oaks Elementary School, 1501 State Rt. 29, Immokalee (Collier County), FL 33934; (813) 657-5115

It is evident that problem-centered learning expects teachers and students to do things differently than in a traditional classroom. Wheatley (1991) outlines the components of a problem-centered lesson:

> *In preparing for class a teacher selects tasks which have a high probability of being problematical for students—tasks which may cause students to find a problem. Secondly, the students work on these tasks in small groups. During this time the teacher attempts to convey collaborative work as a goal. Finally, the class is convened as a whole for a time of sharing. Groups present their solutions to the class, not to the teacher, for discussion. The role of the teacher in these discussions is that of facilitator and every effort is made to be nonjudgmental and encouraging. (pp. 15-16)*

Teachers are the key to effective problem-centered learning, but they will be even more successful if they are encouraged by administrators to try problem-centered approaches. New programs can be designed which recognize the importance of teaching students to think and solve problems, and which allow and encourage teachers to implement problem-centered learning. These teachers will "search for increases in diversity and creativity in student responses as they provide a safe, nonjudgmental classroom environment in which students can risk verbalizing innovative ideas" (Costa & Lowery, 1989, p. 4).

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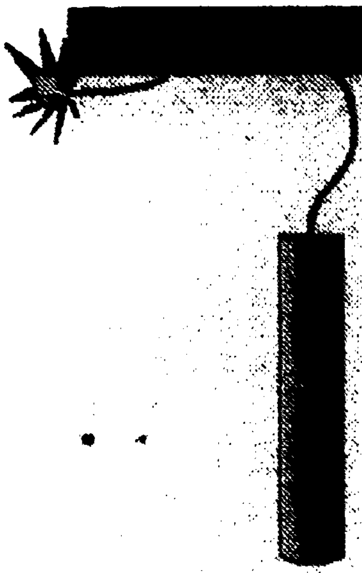
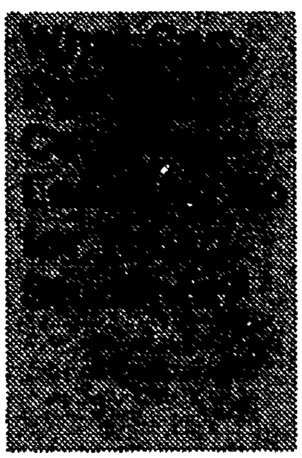


The National Science Resources Center (NSRC)—a joint project of the National Academy of Sciences and the Smithsonian Institution—has initiated a number of activities to help educators teach science with a hands-on approach. They have developed a computerized database of science teaching materials and techniques that have proven effective in classrooms. NSRC has also created 24 modular teaching units for the first through sixth grades; the units use inexpensive, easy-to-find materials that encourage investigation of topics in physical, life, and earth science, and technology. In addition, NSRC has designed Elementary Science Leadership Institutes which bring together teachers and administrators to discuss curriculum design, teacher inservice education, science materials support systems, and student assessment.

CONTACT INFORMATION: National Science Resources Center, 900 Jefferson Drive, S.W., Rm. 1190, Smithsonian Institution, Washington, DC 20560; (202) 357-2555



We have already seen some of the benefits of problem-centered learning for students:

- They learn to view mathematics and science as meaningful activities, and are intrinsically motivated to learn these subjects.
- They become more confident in their ability to learn mathematics and science material.
- They learn to work with each other and the teacher to explore and analyze new information.
- They learn to apply their problem-solving skills to difficult or new activities within the classroom and outside of school.

Other benefits relate to specific aspects of a problem-centered approach. Small-group activities, for instance, boast academic and social advantages over individualized seatwork. By working in small groups, students obtain support from one another as they learn. Small group activities are designed to help all members of the group succeed—not just the few talented individuals who have always performed well—and can be applied at any grade level of science and mathematics curricula, and in all major topics within those disciplines (Slavin, 1985). According to Cobb et al. (1991), certain social norms exist in and are necessary for effective, small-group, problem-solving tasks:

- persisting to solve personally challenging problems,
- explaining personal solutions to . . . partner[s],
- listening to and trying to make sense of a partner's explanation, [and]
- attempting to achieve consensus about an answer (p. 7).

Students working in cooperative groups develop important social skills:

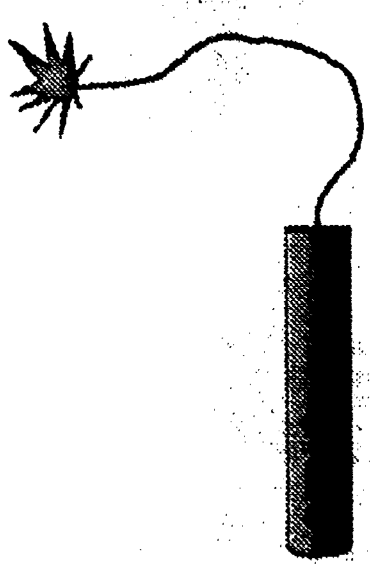
- greater self-awareness and self-acceptance,
- more positive self-esteem,
- better social skills,
- better inter-group relations,
- increased social acceptance of low-ability students, and
- better communication skills with one another and with the teacher (Brilhart, 1986; Davidson, 1985; Johnson, Johnson, & Maruyama, 1983; Webb, 1985; Wheatley, 1991).

Students also benefit from whole-class discussions:

- Students may learn to explain their own methods better; they "elaborate and refine their thinking and deepen their understanding" (Wheatley, 1991, p. 19).
- Through conversation with others, students begin to develop conversations within themselves; in the future, they will be able to include the results of internal dialogue in the problem-solving process.
- Students learn to make decisions for themselves about solutions by choosing among many seemingly acceptable possibilities.
- Students participate in discussions which model professional problem-solving conversations; this reinforces problem-centered learning as good preparation for life after school (Wheatley, 1984, 1991).

The benefits of problem-centered learning are many. The challenge that mathematics and science teachers face, then, is integrating problem-centered learning into their curricula.

DYNAMITE IDEA - Students Learn to Like Like to Learn Science



Teachers at Oakbrook Elementary in Ladson, South Carolina are using a hands-on science program which teaches students to cooperate and solve problems while improving their enjoyment of science. The teachers and the principal, Becky Steedly, conducted a survey at the beginning of the school year which found that science was the students' least favorite school subject. However, after a year of hands-on, small-group activities, a second survey found that science had become the second-most favorite subject. Martha Parrish, a third grade teacher at Oakbrook, used the program to teach concepts related to flight, measurement, and plant growth. Her students enjoyed the activities (such as a paper airplane contest), and learned some of the important concepts through solving problems (such as how to add weight to an airplane to increase its flight distance).

CONTACT INFORMATION: Oakbrook Elementary School, 4700 Old Fort Road, Ladson (Dorchester County), SC 29456
(803) 821-1165

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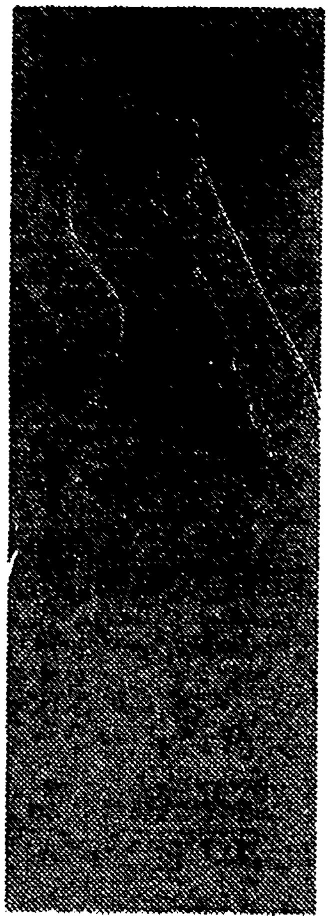

Teachers who want to try problem-centered learning will have many questions:

- What problems are appropriate for problem-centered learning?
- How might a teacher design a lesson using small groups, and how can the groups be best managed?
- What strategies can a teacher use to conduct a whole-class, problem-solving discussion?
- How does a teacher assess student learning after a problem-centered activity?
- What materials are required to conduct a problem-centered lesson?
- How does a teacher use present textbooks to teach with a problem-centered perspective?
- Will a teacher who implements problem-centered learning still be able to cover the entire curriculum?
- How can the teacher garner support for this approach from administration and colleagues?
- How does a teacher ensure that all students participate and contribute positively to the activities of a problem-centered lesson?

Implementing new teaching strategy is a gradual process. It takes time for teachers and students to feel comfortable with any new method, and teachers should not feel compelled to incorporate a problem-centered approach into every lesson, right away. Instead, a transition process should emerge, through which teachers try one component (such as small-group exploration) and then another (such as an alternative form of assessment), until entire problem-centered lessons take shape. Although some textbooks are being published which may aid the teacher in implementing problem-centered learning, most textbooks and materials do not emphasize this approach, and teachers may need to be creative in revising, refocusing, and reordering lessons and course materials. Teachers will also be challenged to identify tasks that embody certain concepts of mathematics or science, and that will also be problematic for students.

Some of the questions that teachers may have about how to use problem-centered learning will be addressed in the following section. But, teachers are bound to have concerns about how to succeed with a problem-centered approach when so many possible obstacles exist. This subsection will discuss some of these obstacles and provide suggestions for how to address them. Of course, teachers cannot be expected to find resolutions in a vaccuum. Successful implementation of problem-centered learning will take the combined efforts of teachers, administrators, staff development coordinators, and students. Many aspects of the learning environment will need to be considered in order to teach with a problem-centered perspective:

each student's level of cognitive development and preferred learning style
This information is critical when choosing problems that all students will be able to solve, or when dividing students into productive, small groups. Teachers can group together high- and low-achieving students so that students can help one another. Other teachers have found that placing students of similar achievement levels into the same group works well because they learn to depend upon each other. Grouping students with the same or different learning styles also change the dynamics of a group. Teachers may want to try different combinations of students, as well as activities which vary in their degree of difficulty, so that each problem-centered lesson requires the development of different problem-solving and cooperative-learning skills. (See the Appendix for more about learning styles and for some suggested learning styles inventories.)

DYNAMITE IDEA - Grouping Students According to Learning Styles

Teresa Dollar, a high school geometry teacher at Shelby County High in Columbiana, Alabama, groups students carefully for problem-centered activities. She begins the year by giving students a learning styles inventory in order to find out whether each student prefers to learn things verbally, auditorially, or through hands-on activities. Ms. Dollar uses this knowledge, and information about their cognitive abilities, to group students in different ways to solve problems. One year she used a geometry text entitled *Discovering Geometry: An Inductive Approach* (Serra, 1989) that does not define concepts; instead, students are expected to work in their groups to define new words and discover geometric concepts. Students initially complained that the book "doesn't tell me anything," but "that means they're thinking," explained Ms. Dollar. (See Section III-Resources for more information about the geometry textbook by Serra.)
CONTACT INFORMATION: Shelby County High School, 101 Washington Street, Columbiana (Shelby County), AL 35051; (205) 669-5640

discipline problems when working with small groups
Suggestions are presented in the next section which will help teachers manage small- and whole-group experiences. Choosing activities which will keep students interested and busy enough to remain on task will help, as well as grouping students in ways which minimize disruption. However, teachers may find that problem-centered learning works better when students feel free to move around and talk to one another. It is important to be sure that all students participate, but this can be difficult with students who have behavior problems or who have neglected other assignments. Teachers may find that problem-centered learning promotes active participation of students who normally do not enjoy school or do not complete assigned tasks. A teacher may want to enlist the help of other group members to encourage a student to participate.

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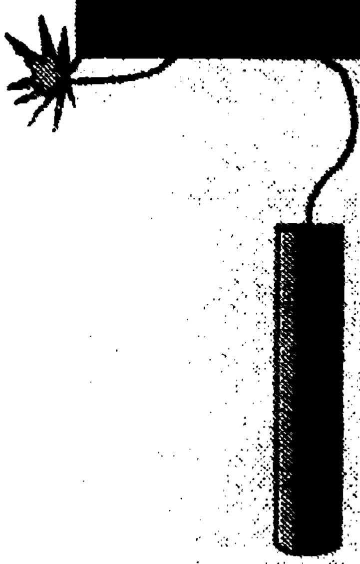
too little time, and too much content

The lack of time in the school day or class period can be frustrating. Secondary teachers often complain that a divided day prevents effective long-term projects, and all teachers feel the pressure to "cover the content." The example on pages 21-23 provides one suggestion on how to structure a multi-day project at the secondary level. The success of problem-centered learning activities depends on setting aside enough time to work on concepts in depth. According to Raizen et al. (1989), "Giving students (or teachers) a choice in the problems students will be asked to solve acknowledges the fact that not everything has to be covered. A premium is placed on depth of coverage—on problems with many parts . . . that require depth of understanding" (p. 61). *Project 2061: Science for All Americans* concurs: "schools do not need to be asked to teach more and more content, but rather to focus on what is essential to scientific literacy and to teach it more effectively" (p. 4). Because students will be learning skills—such as working cooperatively and solving problems—as well as content, they will be developing the capacity to explore new concepts even after they have left the classroom. "It may be less critical to leave out some topics while covering others more fully than to try to cover everything at the expense of the larger goals" (Ivany & Wassermann, 1988, p. 293).

DYNAMITE IDEA: Probing the Depths of Physics



The physics students at N. B. Forrest High in Jacksonville, Florida are learning that depth is more important than breadth when learning about physics. Their teacher, Roderick Dickens, emphasizes that physics is a process; therefore, he gives students time to discover concepts. Little instruction is given before an activity, and students meet in groups of three to use computer data analysis programs to explore new concepts. For example, after students conducted experiments to discover the relationship between force, mass, and acceleration, Mr. Dickens revealed that they had discovered Newton's second law. Mr. Dickens has found that, in his classroom, a student group works best if its members have performed similarly well (or poorly) in the past. The group turns in a single lab report for a grade, so students learn to depend on one another for success.

CONTACT INFORMATION: Nathan B. Forrest High School, 5530 Firestone Road, Jacksonville (Duval County), FL 32244; (904) 771-3000

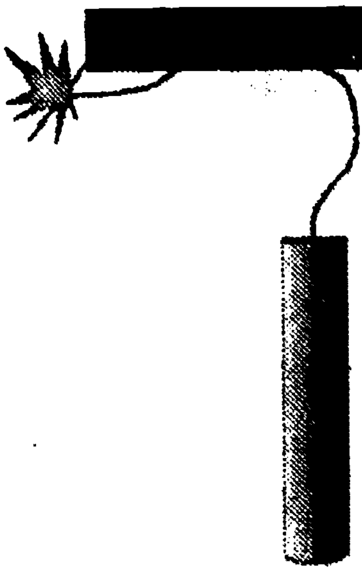
lack of energy or resources to create new lessons

Suggestions and examples in the following section will show that problem-centered learning does not necessitate more planning or gathering of materials than a traditional approach. Modifying lessons while still using existing textbooks and past activities can easily produce a problem-centered lesson. Section III provides a list of teaching programs, resource guides, and activity books which can assist in planning problem-centered lessons.

lack of school or district support for instructional change

While it is only through practice that a teacher can demonstrate the success of a teaching strategy, research results give substantial support to the success of problem-centered learning. Research also reveals, however, the difficulty teachers have in implementing lasting improvements in their instruction without support from colleagues, principals, and district administrators ("Squaring the Root," 1991). Given this fact, staff development coordinators can encourage administrators and teachers from the same school to attend a workshop on problem-centered learning so that they can promote similar goals at the school and provide long-term support to one another. It is also important for administrators to encourage teachers to share successful lesson ideas or strategies.

DYNAMITE IDEA - "Mathematics for the Twenty-First Century"



Teachers at Forest Acres Elementary in Easley, South Carolina are encouraged to use the components of problem-centered learning in their "Mathematics for the Twenty-First Century" project. The main characteristics of the program include using manipulatives, "setting up hands-on situations where students have opportunities to explore and discover," asking questions which require students to think and reason and which may have more than one answer, and encouraging communication through discussions and cooperative learning. The program designers believe that this approach will help children value mathematics and become more excited about learning, while preparing them for work in twenty-first century society.

CONTACT INFORMATION: Patty Smith, Elementary Mathematics Specialist, Forest Acres Elementary School, Easley (Pickens County), SC (803) 855-7865

After becoming familiar with the components of a problem-centered lesson, teachers can begin to think about ways to incorporate these components and may revise their approach to teaching new concepts. Implementation will evolve slowly; components will be included piece by piece, as teachers connect this method to what they are already doing in the classroom and overcome the obstacles to successful, problem-centered learning. However, it is hoped that eventually problem-centered learning will become a prominent strategy in mathematics and science classrooms, and that teachers will employ a problem-centered approach when designing each new unit. In other words, even though adopting problem-centered learning can bring about *revolutionary* change in the classroom, your best path to success is through an *evolutionary* process. Section II discusses the components of a problem-centered lesson and can be used as a guide to implementation.

Research and practice have shown that while problem-centered learning can take many forms successfully, it has four main components which serve as a general, sequential framework. This section explains these components, and provides suggestions for teachers on how to apply them in teaching mathematics and science. Teachers need not feel limited to implementing problem-centered learning using this model, but this structure will provide guidance for planning and practicing problem-centered lessons. Concrete examples and "Dynamite Ideas" provide further suggestions for action. Each component description also includes a summary of a teachers' typical responsibilities during that part of the lesson. The four components are listed below, with brief descriptions of what happens during each:

1) **Posing Appropriate Problems**
   Engages the students in an invitation to learn. This process begins with a question or task from the teacher or with a student's spontaneous question.

2) **Working in Small Groups**
   Engages the students in exploration, discovery, and creation of ideas. Students try to answer questions or solve problems using materials they have collected or that have been provided by the teacher.

3) **Sharing as a Whole Class**
   Allows students to propose explanations and solutions based on their own explorations. Students persuade themselves, as well as their peers, that solutions and new concepts they have generated are based on convincing data from their activities.

4) **Assessing Student Learning**
   Evaluates how well students have learned the skills and concepts that are the goals of a lesson. Alternative assessments allow students to demonstrate that they have integrated the new information into their existing conceptual frameworks (Loucks-Horsley et al., 1990).

1. Posing Appropriate Problems

Problem-centered activities begin with the posing of a question or problem. In order for teachers to properly implement this beginning phase of problem-centered lessons, they need to consider the following:

A. characteristics of appropriate problems,
B. possibilities for modifying traditional problems/exercises, and
C. the teacher's responsibilities.

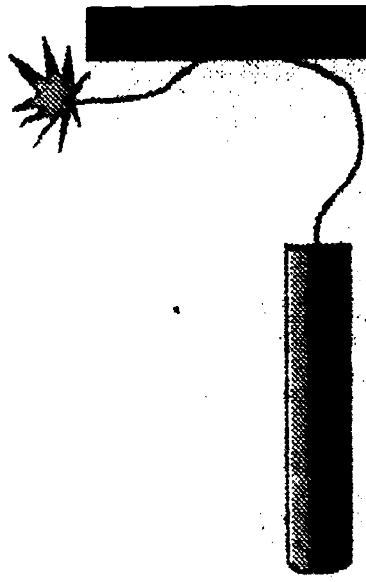
A. Characteristics of Appropriate Problems

Any problem which is introduced should be viewed as a problem by the students. When students are expected to formulate and recognize the right problem to address a question, they are learning a key step of the problem-solving process (Pollak, 1978). Appropriate problems must also entice students to explore solutions. Questions and problematic tasks that relate to the students' personal experiences or interests are usually the most motivating (Cheves & Parks, 1984). McKnight (1989) and Wheatley (1991) suggest some characteristics of appropriate problems for students:

Problem-centered activities should

- be accessible to everyone at the start of the lesson,
- be interesting to the students and related to their actual experiences,
- encourage students to form hypotheses,
- encourage students to use their own methods to modify or transform the materials,
- promote discussion,
- have identifiable patterns,
- have an element of surprise,
- invite students to make decisions,
- have different levels of solutions which can be reached and which students can recognize, and
- be extendable to future classroom activities or to situations outside of school.

DYNAMITE IDEA - A Problem With Multiple Solutions



The following question was designed by a team of teachers for the New Standards Project (which is a joint program of the National Center on Education and the Economy, and the Learning Research and Development Center of the University of Pittsburgh). The problem is intended for tenth-grade, mathematics students, and has no single right or wrong answer. Students can work in groups to solve the problem and present their suggestions to the class.

Problem:

You work in the purchasing department of the PERK Corporation. You are given the responsibility to write a report supporting your

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[illegible]

[illegible] executives. The best negotiated price on a new Cadillac DeVille is $32,688. You are able to finance the car at an interest rate of 10.5 percent over four years with a five percent down payment. The same car can be leased for $499 a month over sixty months with an option to buy that car for $12,224.56 at the end of the fifth year. Include these factors in your report and as many others as you feel are important in making your recommendation.
SOURCE: National Center on Education and the Economy, 1341 G Street N.W., Suite 1020, Washington, D.C. 20005; (202) 783-3668

B. Modifying Traditional Problems

With some creativity and planning, a teacher can use problems from traditional lessons to introduce a problem-centered activity. The teacher can, for instance, try the following modifications:

- move word problems or post-lab questions from the end of a lecture, lab, or unit to the beginning of it,
- re-word exercises in textbooks to make them more relevant to students' current interests,
- modify laboratory activities to include more materials than would be necessary for the expected result, or
- expand word problems to allow for a variety of solutions.

For example, one traditional biology laboratory activity, designed to demonstrate to students the effects of osmosis on living cells, was modified to challenge students and engage them in a real, problem-solving activity. The original activity was designed to be used as a follow-up to a lecture/discussion of the process of osmosis. The laboratory manual provides exact procedural directions—including what solutions to use (salty and distilled water) and what measurements to take—to determine the effects of osmosis on a potato core. After performing the osmosis, the students are asked a series of questions and must describe what they think happened to the core and why the measurements changed.

This lab does not challenge the students to engage in problem solving; it only asks them to follow directions. Most of the students already know what should happen because they have previously been told about the effects of salty and distilled water on living cells. Thus, the results of the experiment will not be a surprise, nor is there likely to be a variety of results or answers unless a student makes a mistake in the procedure. Because the procedure is specified, students are not given an opportunity to explore their own ideas. Furthermore, any discussion about the experiment will relate to making sure that the single right answer to each question is achieved.

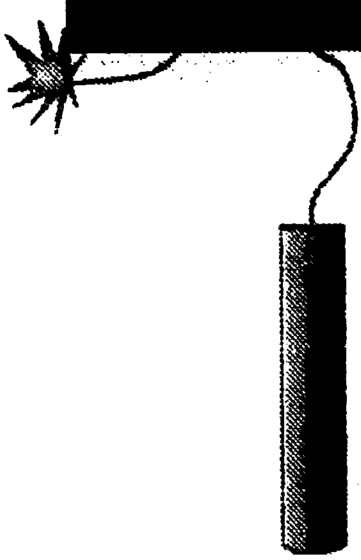
Using this lesson, the following changes could be made to develop a problem-centered activity:

- introduce the activity in the form of a problem prior to beginning any discussion of osmosis or diffusion in the classroom,
- provide a variety of solutes, vegetables (including marine vegetation), and other materials for students' use in exploring osmosis,
- challenge the student groups to design an experiment to find out how to make a piece of vegetable matter change size and to demonstrate the change in some measurable way, and
- encourage the students, during discussion, to think of examples of osmosis from their previous experiences (such as one's skin wrinkling after sustained immersion in water).

C. The Teacher's Responsibilities

The teacher is responsible for assuring that problems are appropriate, and that lessons are properly modified to encourage discovery. However, the teacher may also want to include students in the posing of problems. In order to take advantage of students' curiosity, a teacher could gather questions or ideas from students about a certain topic, and then incorporate them into a future lesson plan. Or students could suggest activities that may help them find an answer to a student's question, and the teacher could try to obtain the necessary materials to allow students to try one of these activities. Teachers can also allow students to choose their own topics for group projects.

DYNAMITE IDEA - Students Design Their Own Mathematics Projects



Student participants in the mathematics department of the Georgia Governor's Honors Program are given a chance to pose and solve problems of their own choosing. The program is a six-week, summer camp that allows selected secondary students to focus on a subject area that interests them. In the first four weeks, students learned about particular mathematical tools and procedures, and practiced solving problems posed by the teachers. In the last two weeks, however, students were able to work in groups on mathematical problems that they designed themselves. Some were abstract questions about lines, curves, and equations, while others utilized camp experiences to create projects, such as a roommate compatibility survey. Dennis Stewart, who directed the mathematics group last summer, believes that all the students used this activity to practice mathematical skills and apply the tools that they had been taught.

CONTACT INFORMATION: Lonnie Love, Administrator of Gifted Programs, Georgia Department of Education, 2050 Twin Towers East, Atlanta, GA 30334-5040; (404) 656-2415

2. Working in Small Groups

After a problem or question has been posed and clarified, students are ready to work in small groups to explore solutions. This stage can provide excellent preparation for the work world because working together in groups on problems provides students with opportunities that are similar to the experiences encountered by mathematicians and scientists in their professions (Johnson & Johnson, 1989). Groups of professionals work together to conduct pure research, or are employed as teams by technological and scientific industries to work on problems of interest to the industry. This is because, as Brilhart (1986) points out, "groups . . . are more effective problem solvers in the long run than are the individuals" (p. 6). Learning to apply and appreciate mathematics and science concepts, then, should involve cooperative group work that promotes an understanding of how such concepts are created and used in the world which students will face when they leave school.

When teachers consider implementing small-group work, the following information may be helpful:

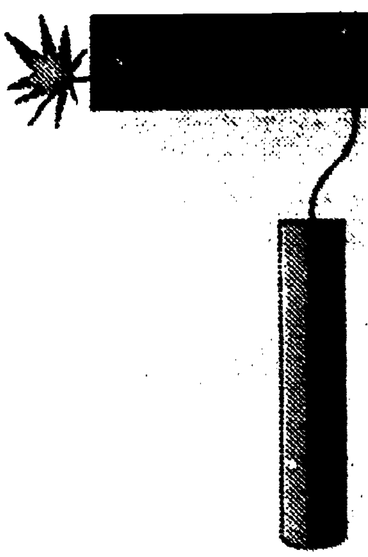
A. the characteristics of effective, small-group learning,
B. the steps involved in creating a small-group activity, and
C. the teacher's responsibilities before and during a small-group activity.

A. Characteristics of Effective, Small-Group Learning

A small-group experience is most effective when it is designed to give students autonomy in choosing a course of action, and when it allows students enough time to explore more than one method to solve a problem. Brilhart (1986) suggests some necessary ingredients for effective, group problem solving:

- group members should bring diverse experiences, knowledge, and skills to the task,
- resources and materials for solving the problem should be available,
- an appropriate setting for productive work should be provided, and
- members should feel committed to solving the problem.

A teacher can help to satisfy these conditions by grouping students appropriately, gathering materials in advance, arranging the classroom properly, and choosing problems that are meaningful to students.



DYNAMITE IDEA - Planning an Effective Small-Group Experience

Betty McBride teaches science to seventh and eighth graders at East Choctaw Junior High in Butler, Alabama. Ms. McBride groups her students carefully so they can help one another. By using mixed-ability small groups, she encourages high achievers to help low achievers understand the instructions, procedures, and results. She also designs activities so that every member of the group can become involved. For example, when beginning a lesson on mineral identification, student groups are expected to perform a number of identification tests on unlabeled minerals; each student has to perform at least one of the tests and the whole group has to agree on the identification of the minerals that they are given.

CONTACT INFORMATION: East Choctaw Junior High School, Butler (Choctaw County), AL 36904; (205) 459-3520

B. Creating a Small-Group Activity

When designing a problem-centered learning activity, the teacher will want to prepare carefully for the small-group exploration phase to assure that the lesson runs as smoothly as possible. In *Circles of Learning: Cooperation in the Classroom* (Johnson, Johnson, Holubec, & Roy, 1984), the authors suggest five tasks for teachers to consider as they implement group activities. These tasks are presented below along with related questions that may help in the planning process. Each task is further clarified by an example from a high school chemistry lesson which was created by Karen Robblee, a teacher in Raleigh, North Carolina (Robblee, 1991).

1. **Clearly specify the objectives for the lesson.**
   a. What are the academic objectives and at what level are they to be achieved?
   b. What collaborative skills objectives will be emphasized?

   Ms. Robblee designed a problem-centered lesson because she wanted her students to master stoichiometry problems, while participating more in the learning process and working cooperatively. She hoped that they would learn to enjoy chemistry more and see its relevance. Lastly, she was looking for a teaching method that would help her get control of an increasingly disruptive class of students who mostly "preferred to talk with their friends or ask distracting questions" (p. 20). The assignment for each group was to represent a company that manufactured and sold hydrogen gas, and to submit bids to a customer (the teacher) of the best three ways to produce a large supply of hydrogen for use in manufacturing ammonia.

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2. **Make decisions about placing students in learning groups before the lesson is taught.**
   a. What size group will be most effective for the time and materials available?
   b. Who should be placed in each group and what criteria should be used for placement? Or should students be allowed to form their own groups?
   c. How long should the groups stay together?
   d. How should the room be arranged to facilitate collaborative interaction?
   e. How should materials be distributed to help students understand that they are in a situation that requires interdependence?
   f. Which students should be assigned what tasks?
   g. How will the groups be managed to maintain order and encourage maximum interaction?

   Ms. Robblee decided that groups of students who did not ordinarily interact would work best, because they would be "more likely to focus on the assignment rather than their plans for the weekend" (p. 20). The groups consisted of four members each, and Ms. Robblee explained that each member would assume a different role in the problem-solving task; each student would be the manager of either marketing, manufacturing, quality control, or personnel. The final bids were due three days after the activity began, so groups worked together for most of three class periods. No laboratory materials were required for this assignment.

3. **Clearly explain the task, goal structure, and learning activity to the students.**
   a. How much instruction do students need to understand what to do?
   b. What form will the final product produced by the group take—a single written report or paper, an oral report, a model?
   c. How will each member be held accountable for his/her own learning?
   d. What will be the criteria for success?
   e. How will cooperation be defined in terms of behavior that is appropriate for group members?

   In Ms. Robblee's class, students were at first daunted by the complexity of the problem, and required a lot of encouragement and guidance from their teacher. But with some suggestions for steps to follow (brainstorming, narrowing possibilities, evaluating ideas), students became challenged by the problem, and some rejected offers of assistance from the teacher. At the end of each class period, individual students put their work into folders which were given to the teacher in a team envelope. This allowed Ms. Robblee to check each student's work. At the end of the project, each team submitted a single bid. The team which best met all the requirements of the activity received credit for one homework assignment, but each team received an award for a particular strength of their bid (such as a Safety Award).

4. **Monitor the effectiveness of the cooperative learning groups and intervene to provide task assistance or to increase students' interpersonal and group skills.**
   a. What means will be used by teachers and students to monitor cooperation?
   b. What kind of assistance should the teacher provide when answering questions or interacting with the group in other ways?
   c. What interventions by the teacher are appropriate when group cooperation goes awry?

The team envelope, which was submitted at the end of each class period, allowed Ms. Robblee to monitor the group's progress and ability to coordinate efforts. During the class period, she "circulated about the room answering questions and verifying the accuracy of [student] calculations" (p. 23). In addition, the team "Personnel Manager" was expected to promote cooperation and provide encouragement to the rest of the team.

5. **Encourage students' achievement and help students discuss how well they collaborated with each other.**
   a. What is the best way for students to evaluate their own group interaction?
   b. Should the whole class be involved in discussing the quality of group interactions?
   c. How much time should be allotted to discussing group functioning?

Ms. Robblee assessed students' attitudes about the assignment and about cooperative learning by talking to individuals or the whole class during and after the activity. One student observed that, "People who don't usually do anything are helping." Another said, "This sure beats class notes" (p. 23). When the activity was completed, Ms. Robblee believed that her students had "learned new ways of sharing information and learning from each other" (p. 23).
CONTACT INFORMATION: Karen M. Robblee, Millbrook High School, Raleigh, (Wake County), NC (919) 850-8787.

DYNAMITE IDEA - Small-Group Activities for Elementary Students

Judy Rucker, a teacher at Hope Valley Elementary in Durham, North Carolina, has been using small groups for years to teach mathematics and science. She has created a number of problem-solving activities for groups of second and third graders, which are easy for teachers to implement. For example, Ms. Rucker gives students graph paper to cut out shapes made of even or odd numbers of squares, and then asks them to use these shapes to write an explanation of even and odd number concepts. She also uses groups to practice classification of rocks, leaves, or pictures, and gives students index cards on which to write their classification rules. When studying the planet Earth,

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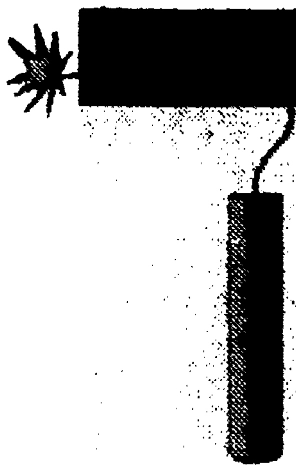
students work together to compare the characteristics of Earth and an apple. And, in a lesson about shadows and light, students use blocks and flashlights to create the longest and shortest shadows that they can; they measure them and compare them across groups. Ms. Rucker uses each of these activities to introduce or further explore a mathematics or science concept, and follows them with class discussions and student presentations.
CONTACT INFORMATION: Hope Valley Elementary School, 3023 University Drive Durham (Durham County), NC 27707; (919) 560-3932

C. The Teacher's Responsibilities
Teachers who integrate small-group activities into their instruction assume new and enhanced roles from those in a more traditional classroom:

- they teach students cooperative skills;
- they model communication skills, such as discussion, elaboration, acceptance of diverse views, and negotiation of meaning;
- they establish an appropriate environment for exploration, in which students are allowed to work productively in small groups without constant monitoring (Cobb et al., 1991);
- they encourage persistence among group members, so that students arrive at solutions which make sense to all of them; and
- they evaluate the task in light of their goals for the lesson, and make any necessary modifications.

While student autonomy should be encouraged, the teacher can provide guidance and monitoring of groups to assure that each student is participating, and no one student is doing all the work or being left out. One way to do this, as Ms. Robblee demonstrated, is to assign each student in the group to a particular task, or to require individuals to report on their progress at the end of each class period. Teachers may also need to provide guidance to groups that "get stuck" in the middle of the problem-solving process. Teachers can provide hints about solutions, or may suggest a number of tasks that may help the group proceed, such as brainstorming, talking with other groups about methods that they are trying, or attempting to use materials in different ways.



DYNAMITE IDEA — Science is Elementary, where Students Divide the Tasks

Elementary and middle school teachers in Broward County, Florida are using a program called "Science is Elementary" which emphasizes solving problems the way scientists do in the real world. Students working in teams of four assume different roles to explore topics introduced by the teacher. A team member can divide the tasks, gather the necessary materials, record the data, or play the "industrial spy" (who looks at what other teams are doing and reports

to his/her own group). Students learn about cooperation and team effort, because if one student does not participate, it adversely affects the success of the team. "Science is Elementary" emphasizes curiosity and creativity; any questions students have about the topic are "fair game," says science supervisor Angie Matamoros, and all answers are considered in the solution.
CONTACT INFORMATION: Angie Matamoros, Lead Science Supervisor, Broward County, FL (305) 765-6367

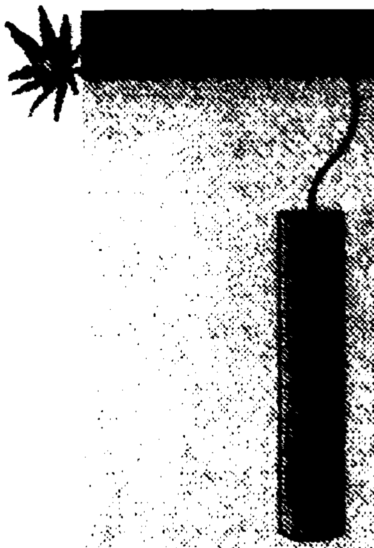
3. Sharing as a Whole Class

After a period of small-group interaction and exploration, the students should be reconvened for a time of sharing. Students may have invented many ways to reach a viable solution, and should be encouraged to discuss their strategies and discoveries. This subsection includes the following:

A. characteristics of effective whole-class discussions,
B. implementing whole-class sharing in a problem-centered lesson, and
C. the teacher's responsibilities during whole-class discussions.

A. Characteristics of Effective Whole-Class Discussions

A goal of class discussion is consensus; students attempt to agree on solutions which make sense to all of them. When implementing this phase of a problem-centered activity, teachers will find that the success of a whole-class discussion is almost entirely dependent on their own behaviors as facilitators. Whole-class discussions which follow small-group exploration are most effective in helping students negotiate acceptable conclusions when all students are given an opportunity to share their small-group experiences and their ideas about the solution, actively listen to and consider others' contributions, and are allowed, if they wish, to use the chalkboard, overhead projector, manipulatives, or other materials to clarify their explanations (adapted from Brilhart, 1986).



Cindy Austin, a third grade teacher at Catawba Springs Elementary in Denver, North Carolina, begins a whole-class discussion of solutions to a mathematical problem by allowing students to use the bulletin board to display their answers. For example, Ms. Austin may ask students to work in pairs and devise several ways of adding money to get one dollar and 43 cents. Using paper and rubber stamps of coins and dollar bills, students decide on a number of solutions. Ms. Austin then asks students to bring certain solutions to the bulletin board to be discussed, such as those which used a dollar bill, or those which used more than 15 coins. This allows students to see each others' ideas, to discuss their solutions with one another, and to suggest further possibilities. Ms. Austin can use such an activity to introduce a variety of mathematics lessons.

CONTACT INFORMATION: Catawba Springs Elementary School, 1701 Little Egypt Road, Denver (Lincoln County), NC 28037; (704) 483-2404

B. Implementing Whole-Class Sharing in a Problem-Centered Lesson

The use of a whole-class discussion in a problem-centered lesson is best represented by the following excerpt taken from a study by Yackel, Cobb, Wood, Wheatley and Merkel (1990). The excerpt also demonstrates the supportive role of a teacher in a problem-centered mathematics activity.

> *The class was working on a whole-class activity in which the teacher asked the children to try to figure out the answer to 9 + 9 + 9 without counting. The first child to offer a solution added 10 plus 10 plus 10 and then subtracted three ones to get 27. The next solution was offered by Mike.*
>
> ***Mike:*** *I changed one 9 to 10 and one 9 into a 17 and then I took away one 9 and then I came up with 27."*

Instead of treating this as a confused and muddled manipulation of numbers, the teacher assumed that Mike was attempting to communicate meaningful thinking. First she signaled this assumption with her comments, and then she proceeded to try to figure out what Mike might have been trying to say:

> ***Teacher:*** *"Did you hear that, Jennie? Run that - okay, now listen I may need your help. [to Mike] I want you to say it again. You said you took one 9 and turned it into a 10."*
>
> ***Mike:*** *"And I took nine—I took seven . . . —and changed the second 9 into a 17."*
>
> ***Teacher:*** *"Change that [pointing to the second 9] into a 17."*
>
> ***Mike:*** *"And I took away that last 9 into an equals and then I came up with 27."*

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Again, the teacher might assume that Mike does not know what he is talking about. However, she continues to assume that what he did made sense to him, and helps him develop an explanation that might make sense to the other children.

Teacher:	*[to the class] "Do you see how he did it?*
Adam:	*"He took away —it away from the last 9 and put it to that [the first 9]. Added that 8 to the 9 and got 17.*
Teacher:	*"Let's take a look at this part of it [pointing to the last two 9s]. What's 9 + 9?"*
Students:	*[in unison] 18.*
Teacher:	*18. Okay. He knew that 9 and 9 made 18. Okay, he knew that. Now, he took 1 away from 18 and what does that give us?*
Students:	*[in unison] 17.*
Teacher:	*"17, and he took the 1 that he had over here . . . and he added it to this 9 (the first 9) and that made 10. That was a way to figure it out." (pp. 16-17)*

The way in which the teacher pursued the discussion with Mike was viewed by Yackel, et al. (1990) as having several positive effects. By not judging Mike as incorrect but rather assuming that he was engaged in meaningful activity, the teacher helped Mike to reflect on his solution, thereby attempting to evaluate it himself. In addition, the entire class had the benefit of thinking through another solution method. Students may then have considered the viability of their own answers. Thus, during a time of whole-class sharing, the teacher and the students were involved together in negotiation to construct concepts which made sense.

DYNAMITE IDEA - Using Whole-Group Discussion to Explore Lake Pollution

Some teachers and students in Lake County, Florida have the opportunity to practice whole-group negotiation and problem-solving skills at the county's Environmental Resource Center, directed by Carl Hendrick. The day-long activities that the center offers have become so popular that Mr. Hendrick has had to limit visits to only fifth and seventh graders, and high school biology or environmental science students. While in a boat on the lake, students work in pairs to conduct water pollution tests, but all discussions—such as why analyses of water conditions are important, what tests students could conduct on the lake, and what results indicate—are discussed by the whole group. This encourages everyone to share their results and ideas, and allows Mr. Hendrick to guide the discussion so that students are challenged to question how the lake may have become polluted or what they can do to help address the pollution problem. CONTACT INFORMATION: Environmental Resource Center, 320 Lakeshore Drive, Eustis (Lake County), FL 32726; (904) 357-0914

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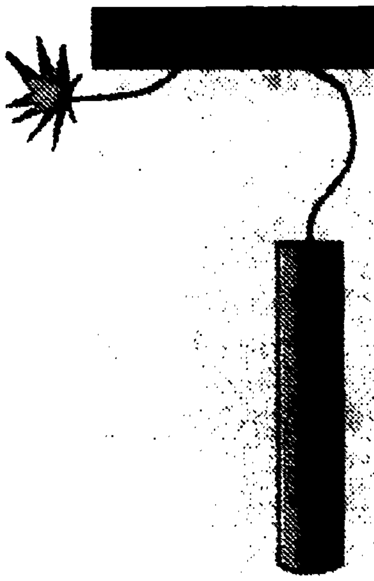
C. The Teacher's Responsibilities

Successful, whole-class sharing after a problem-centered activity requires the teacher to do the following:

- withhold judgment or evaluation of students' suggestions,
- make it clear to the students that s/he assumes their solutions make sense,
- help students filter out irrelevant information or observations,
- encourage students to explain and elaborate upon their suggested solutions,
- reassure students that s/he will help them as they try to verbalize their solution attempts, and
- assist students to reflect on their answers and attempt to evaluate them for themselves.

Students may disagree about methods and solutions, but if the students are given enough time to explain their procedures clearly, discussion with other students will usually reveal whether methods and conclusions are acceptable or not (Wheatley, 1991). The whole-class discussion is also an appropriate format for the teacher to introduce and define new terminology, which the students are then encouraged to use when discussing their methods and results (Knight, Altman, Carpenter, & Rachelson, 1990).

DYNAMITE IDEA - Challenging Students to Explore Further



Tim O'Keefe, a second grade teacher at Nelson Elementary in Columbia, South Carolina, uses whole-class discussions to clarify information that students present. For instance, one day a group of students presented the results of a class survey which explored students' opinions about which of two dinosaurs would win in a dinosaur fight. Mr. O'Keefe challenged the students to present the survey results in a graphic format. He also asked other members of the class to further explain what the results showed, and to explore what the information did not reveal. This presentation was followed by library research about dinosaur behaviors and defenses.
CONTACT INFORMATION: Lonnie B. Nelson Elementary School, 225 N. Brickyard Road, Columbia (Richland School District Two), SC 29204; (803) 736-8730

4. Assessing Student Learning

Although assessment need not take place after every lesson, the last component of a problem-centered approach is to assess students' achievement, skills, and understanding of the concepts. All classroom assessments should accurately measure how well the students and teacher have achieved the goals of the lesson (Archbald & Newmann, 1988; Slavin, 1988). Traditional multiple-choice, fill-in-the-blank, and matching questions on

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tests are inadequate for assessing the goals of a problem-centered lesson. "Traditional tests have been faulted for neglecting the kinds of competence expressed in authentic, 'real life' situations beyond school—speaking, writing, reading, and solving mechanical, biological, or civic problems" (Archibald and Newman, 1988, p. vi). According to Resnick (1987) "most current tests favor students who have acquired lots of factual knowledge and do little to assess either the coherence and utility of that knowledge or the students' ability to use it to reason, solve problems, and the like" (p. 34). Development of higher-order thinking skills is not encouraged by such tests, and students focus more on making a high score than on understanding the material.

The following information deserves consideration when deciding on appropriate assessments:

A. characteristics of effective forms of assessment,
B. possibilities for creating and modifying assessments, and
C. the teacher's responsibilities.

A. Characteristics of Effective Assessments

Due to the inadequacies of traditional assessments and the broad objectives of a problem-centered lesson, alternative assessment strategies are more appropriate for problem-centered activities. Raizen et al. (1989) suggest the following guidelines for ideal assessments in a science classroom. These could be modified and applied to mathematics as well:

- Assessment exercises would be indistinguishable from good instructional tasks.
- Exercises would include hands-on performance tasks to allow students to demonstrate their proficiencies in laboratory and science thinking skills.
- Assessments would strive to probe the student's depth of understanding as well as mastery of a body of knowledge.
- The emphasis would be on both the approach and the product, on how an answer was obtained or a hands-on activity carried out, and on the "correctness" of that answer or performance. (p. 54)

B. Possibilities for Creating or Modifying Forms of Assessment

Many assessment strategies can be implemented during or after a problem-centered activity. The following possibilities are discussed in this section:

- individual activities,
- observation,
- appropriate testing,
- problem-solving measures, and
- small-group activities.

❑ Individual Activities

Some alternative assessment techniques that might be more appropriate for problem-centered learning include the following:

- journals
- essay tests
- portfolios of student progress
- project presentations
- original experiments
- presentations of models
- oral interviews

Such assessments may allow individual students to demonstrate their problem-solving abilities in ways which simulate the application of mathematics and science in real-world situations (Lawrenz, 1991).

DYNAMITE IDEA - Assessing Gradual Learning

Karl Hook, at the Florida State University School—FSU's developmental research school—in Tallahassee, uses problem-centered learning and alternative assessments in his eighth-grade science classroom. For instance, a unit on light may begin with questions such as "What do you want to know about light?", "What do you need to know about light?", and "What do you think the teacher wants you to know about light?" In small groups, students gather the information that they have decided is needed to learn about light. This may involve using textbooks (at least three per concept) to discover the ways that different authors explain the concept. Also, students design and conduct experiments to demonstrate the concept or test a hypothesis. During this process, students prepare pages of a scrapbook which describe and illustrate concepts about light which they have been learning. Throughout the year, the students keep journals which contain notes about each day's activities and how the learning of new concepts may have changed students' views of the world. Mr. Hook also uses oral interviews with small groups to measure understanding and discover misconceptions. Presentations and slide shows by the students are other common means of assessment in this class.

CONTACT INFORMATION: Florida State University School, West Call Street, Tallahassee, FL 32306; (904) 644-1025

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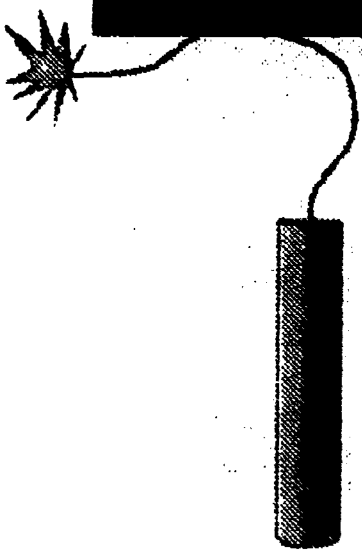
❑ Observation

During the assessment process, teachers can also record observations of each student's behavior and participation during problem-centered learning activities. One way the teacher can do this is to carry index cards during the day and make brief notes about students' behaviors. These observations can be made during problem-centered activities and later during other assessments, such as presentations. Teachers can review these at the end of the day to add comments and file the cards for future use in assigning grades (Raizen et al., 1989).

DYNAMITE IDEA - Observing Student Problem Solvers



Sally Crissman at Shady Hill School in Cambridge, Massachusetts asked her fifth-grade students to solve the problem of a fictitious local restaurant owner. She told them to recommend the best brand of paper towel to use in his restaurant. The students, working in groups, designed and carried out experiments which tested a number of variables that they considered of value in a good paper towel: absurbency; wet strength; dry strength; cost per roll, per sheet, and for total area. They recorded their findings and made recommendations based on interpretations of the data. The teacher watched how the groups of students worked together, made decisions, and resolved difficulties. She noted her observations of students' interactions in her journal and used them as part of the assessment.

CONTACT INFORMATION: Shady Hill School, 178 Cooledge Avenue, Cambridge, MA 02138; (617) 868-1260

SOURCE: Raizen et al., 1989

❑ Appropriate Testing

As testing is still a necessary form of assessment in a classroom, the following questions may be helpful when creating or reviewing science or mathematics tests:

- Are problems included that expect students to think about and analyze situations?
- Does the test include sets of problems that allow students to use more than one step to arrive at a solution?
- Are problems with more than one correct solution or with open-ended solutions included?
- Do opportunities exist for students to formulate problems and use their own data?
- Are students expected to use a variety of approaches to solve a problem?
- Can thinking and practice skills be assessed through exercises calling for hands-on activities?
- Does the test include problems that contain purposely missing or mistaken information and that ask students to find errors and critique the problem? (Raizen et al., 1989, p. 63).
- Are students given credit for their methods as well as their answers?

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EXAMPLE 1-A: [illegible]
Mathematics [illegible]

> **The 1989-90 version of California's twelfth-grade mathematics test includes open-ended questions for students. One question, for example, three geometric shapes, and side lengths and angle sizes for each shape. "Students are asked to identify any inaccuracies in the information that's supplied, as well as explain the inaccuracies" (Toch, 1991, p. 230). Students' answers should note, for instance, that the degrees given for the angles of the triangle are erroneous because they do not add up to 180°. Such questions were also added to California's eighth-grade mathematics test in 1990-91.**
> **SOURCE: Toch, 1991**

If a teacher chooses testing as a form of individual assessment, the tests can be more revealing if they are designed to pinpoint students' misconceptions, as well as understandings, of science and mathematics concepts. Misconceptions are difficult to diagnose with standard classroom tests, but tests which ask students to explain what they were thinking when they gave an explanation provide opportunities for students to express misconceptions and for teachers to identify them (Almy & Genishi, 1979).

☐ Problem-Solving Measures

When attempting to assess problem-solving skills, the teacher may present a series of problems with varying structures or amounts of information. The teacher can request that students write only in pen so that all the steps they use to solve a problem can be reviewed. Observations of students working in groups will also be useful for this purpose (Raizen et al., 1989).

Archbald and Newmann (1988) propose the use of essay and oral examinations to assess problem-solving skills as well as content knowledge. For example, after a unit on ecology and pollution, a teacher could request an oral or written response to the following problem:

> *Mary is going to hike into a lake in the Oregon Cascades. Fifteen years earlier, Mary had been to the same lake to conduct a study for the Oregon Fish and Wildlife Commission. At that time the lake was a typical high mountain lake surrounded by coniferous trees on three sides and some alders, birches, and maples on the more level, meadow side of the lake. The lake had been a favorite fishing spot for her father and grandfather, producing many shrimp-fed rainbow trout. She learned that crawfish from the lake were good bait for the fish.*

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Describe the changes you think might have occurred in the plants and animals of this environment if acid rain had significantly affected the area (p. 14).

Archbald and Newmann recognize that time constraints make these types of tests difficult to use, but suggest that assessments which are designed primarily to measure problem-solving ability can be staggered throughout a course of study, by assessing only a few students at a time.

DYNAMITE IDEA - Assessing Problem Solving Skills

Mary Davidson, a teacher of advanced biology at the Mississippi School for Mathematics and Science in Columbus, found that beginning the school year by letting small groups of students design and complete a project allowed her to assess the students' problem-solving skills. One group used balloons to measure the vital capacity of male/female, athletic/non-athletic students in their school. Another discovered the density difference between diet and sweetened soda, and a third group explored whether the belief in ESP influences one's ESP ability. Small-group presentations and reports summarized students' findings and provided the teacher with information about students' problem-solving abilities. The projects also allowed students to experience the way research is done in the work world, while becoming prepared for later class activities.
CONTACT INFORMATION: Mississippi School for Mathematics and Science, P.O. Box W1627, Columbus, MS 39701; (601) 329-7360

☐ Small-Group Activities

When assessing the work of student groups, using small-group activities for assessment as well as for instruction is pedagogically sound and practical. However, when students are working together, it may be difficult for teachers to quantify learning outcomes and assign marks or grades to individuals. The responsibility for participation and learning rests largely with the students, but the teacher must still assess whether learning is taking place in a group.

With some creativity from students and the teacher, a variety of group assignments are possible. A small group could, for instance,

- conceive of and conduct an experiment for the class,
- produce a scrapbook or comic book which describes how they solved a problem,
- plan and teach a mathematics or science lesson to the class, or
- develop books for use in teaching science or mathematics concepts to younger children.

The teacher may choose to give one grade for the project to the whole group, and use a different assessment tool to assign individual grades.

DYNAMITE IDEA - Final Group Projects

At the end of the school year at Bradshaw High in Florence, Alabama, students in Carolyn Eck's geometry class conduct group projects of their own choosing. Ms. Eck requires that projects relate to the concepts that they have been studying (such as measurement) and that the work be done outside of the classroom. Problems students have posed for themselves include the following:

> What is the total volume of the lockers in the school?
> How much carpeting will the library require?
> How many square feet of parking is available to students at school?
> What is the area inside the running track?

Group reports allow Ms. Eck to assess computational and problem-solving skills, while group presentations reveal findings to the whole class. Ms. Eck said that her students enjoy the opportunity to do a group project that they design themselves.
CONTACT INFORMATION: Bradshaw High School, 1201 Bradshaw Drive, Florence (Lauderdale County), AL 35630; (205) 764-8821

C. The Teacher's Responsibilities

With any lesson, a teacher is expected to choose assessments which are appropriate for the goals and design of the lesson. When assessing student learning after a problem-centered activity, teachers will want to carefully consider the combination of assessments which will reveal the most about students' acquired and deficient knowledge and skills. Designing new and alternative assessment strategies can be time-consuming for the teacher, and may initially seem to be more trouble than it is worth. However, much of the enjoyment and autonomy which a problem-centered activity can provide for students may be forsaken if the students must still worry about memorizing the definition of a concept or about getting the right answers on a test.

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In conjunction with the pilot testing of a new sixth-grade science curriculum, the SouthEastern Regional Vision for Education (SERVE) Laboratory is working with three teams of middle school science teachers to develop science-related performance assessment items. The new science curriculum emphasizes hands-on activities, and will serve as a vehicle for training teachers in performance assessment. The teams of teachers will become partners in developing training materials on performance assessment that will be field-tested, revised, and disseminated in the Southeast. The materials will provide assistance to teachers who wish to incorporate performance assessment methods into teacher-made tests. CONTACT INFORMATION: Wendy McColskey, Research Program Manager, SERVE, P.O. Box 5367, Greensboro, NC 27435; 800-755-3277

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Mathematics and Science Education Programs

AIMS

The AIMS program uses a model of learning which includes "real world" experiences for students, oral and written communication, pictorial or graphic communication, and critical thinking. Useful for enriching the entire curriculum, AIMS was developed for use in teaching mathematics and science. Its emphasis on such skills as observation, illustration, analysis, and application make it easily adaptable to the goals of a problem-centered classroom.

AIMS Educational Foundation
P. O. Box 8120
Fresno, CA 93747
(209) 255-4094

Hands-On Elementary Science

Hands-On Elementary Science is a curriculum which teaches science concepts to 1st through 5th grade students. It emphasizes the development of science processes through the use of problem-solving activities. Four units are introduced at each grade level with topics such as seeds, insects, electricity, and bio-communities. The program includes curriculum guides and materials kits.

Dean A. Wood
Dissemination Center for Hands-On Elementary Science
Hood College
Frederick, MD 21701
(301) 663-3131 ext. 205 & 350

Informal Science Study (IfSS)

IfSS provides 5th through 12th grade teachers with mini-units on various physical science concepts such as acceleration, forces, gravity, time, and conservation of energy. Concepts are presented by relating them to concrete experiences such as amusement park rides, sports, and playground games. Student dialogue is emphasized, and science terms are not defined until after students have explored the concept.

Howard Jones
Project Director
National Training Network
1140 Boston Avenue
Longmont, CO 80501
(303) 651-0833

JEFFCO Middle School Life Science Program
This is a full-year life science curriculum for 7th and 8th grades. It emphasizes a learning cycle of exploration, concept formation, and application and encourages the development of thinking skills when learning science concepts. Textbooks and materials are designed for use in a classroom that contains basic laboratory equipment.

Sharon Close
Jefferson County Public Schools
1829 Denver West Drive, Building 27
Golden, CO 80401 (303) 273-6561

Life Lab Science Program
The Life Lab Science Program, developed by elementary teachers in Santa Cruz, introduces science as a way to solve problems. Based on the idea that gardening can be adapted to many science lessons, students and teachers collaborate to transform their school grounds and/or classrooms into garden laboratories; they can create outdoor gardens, indoor grow boxes, and even a one-acre farm. Students participate in such activities as analyzing the nutrient content of soil, producing compost for fertilization, and planting and harvesting vegetables.

Lisa D. Glick
Program Director
1156 High Street
Santa Cruz, CA 95064
(408) 459-2001

Project WILD
"Project WILD is an interdisciplinary, supplementary environmental and conservation education program" for all grade levels (Project WILD, 1983, p. iii), which teaches students about the relationships between humans, wildlife, and Earth. With Project WILD activities, students discuss, brainstorm, play games, observe their environment, and more. Many aspects of this program are adaptable to a problem-centered approach.

Western Regional Environmental Education Council
Salina Star Route
Boulder, CO 80302
(303) 444-2390

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The following programs are described in

Lee, C. S. (Ed.). (1991). *Mathematics education programs that work: A collection of proven exemplary educational programs and practices in the National Diffusion Network.* Washington, D. C.: Office of Educational Research and Improvement.

Comprehensive School Mathematics Program (CSMP)

CSMP uses game-like and story settings to lead students (grades K-6) through problem-solving activities. Flexible enough to use with whole class, small-group, or individualized instruction, CSMP sequences the content of its curriculum so that students experience mathematics as a spiral of "interlocking experiences."

Clare Heidema
Director
CSMP
12500 E. Iliff Avenue, Suite 201
Aurora, CO 80014
(303) 337-0990

Decision-Making Math (DMM)

"Decision-Making Math is a supplementary program designed to teach 7th, 8th, and 9th grade students a step-by-step plan in order to solve math problems successfully. . . . A variety of methods is used to ensure understanding, such as: questioning and planning, interpreting and verifying, solving problems within a cooperative learning environment, organizing and manipulating data, and analyzing and applying solutions. All emphasis throughout the program and the training is on process rather than solution (p. 9)."

Laura Dunn
Kristine A. Shaff
Co-directors
Education and Technology Foundation
4655 25th Street
San Francisco, CA 94114
(415) 824-5911

Sci-Math

"Sci-Math uses the mathematics of rates and ratios to simplify and unify problem-solving in science, mathematics, and everyday life (p. 14)." As a supplement to science or mathematics curricula in 7th through 12th grades, Sci-Math uses activities related to school, home, or play to teach the technique of factor analysis or labelled rates and to apply it to meaningful problems.

James P. McAuliffe
Sci-Math Director
Education and Technology Foundation
4655 25th Street
San Francisco, CA 94114
(415) 824-5911

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SITE: Successful Inservice through Turnkey Education

SITE is a mathematics inservice program for 2nd through 6th grade teachers (and their students) which uses a problem-solving, hands-on approach to teach higher-level thinking skills and new mathematical concepts. "Since teachers 'teach as they were taught,' the program uses processes and activities which are immediately applicable in the classroom as the instructional model. SITE activities are readily integrated into the existing school mathematics curriculum and mesh with every textbook."

Dr. Barbara Berman
Dr. Fredda J. Friederwitzer
Co-directors
Project SITE
Educational Support Systems, Inc.
Staten Island, NY 10314
(718) 698-3636

Sound Foundations

Sound Foundations was designed for use with remedial or basic skills high school mathematics classes, but can be adapted to 7th and 8th grade programs. Sound Foundations replaces the traditional mathematics curriculum with a simulation game that explores topics such as measurement, graphing, and consumer mathematics. Students become managers of a rock band, are given a budget of $41,000, and must manage the band's finances while organizing concerts, publicity, and record sales.

Robert Gerver
North Shore High School
450 Glen Cove Avenue
Glen Head, NY 11545
(516) 671-5500

For descriptions of other education programs, see

Sivertsen, M. L. (Ed.). (1990). *Science education programs that work: A collection of proven exemplary educational programs and practices in the National Diffusion Network.* Washington, D. C.: Office of Educational Research and Improvement.

Resource Books and Catalogs

National Center for Improving Science Education. (1991). *Resource guide: Mathematics, science, and technology education.* Washington, D. C.: Author.
This resource guide provides an annotated list of organizations, associations, and publications offering useful information and assistance to improve mathematics, science, and technology education. It also lists resources on improving equity in education. Resources include publications from educational organizations, ERIC, the Educational Testing Service, NASA, the U.S. Department of Energy, the National Science Foundation, the National Research Council, and others.

National Science Resources Center. *Science for children: Resources for teachers.* Washington, D. C.: National Academy Press.
The National Science Resources Center compiled this annotated elementary science resource guide from their computerized database of science curricula and teaching materials. It includes curriculum materials for teaching life, earth, and physical science, health, and human biology. Lists of science activity books and magazines for children and teachers are also included. A resource guide for middle school science teachers is under development. Available for $9.95 (less for quantity orders) from the National Academy Press, 2101 Constitution Ave., Washington, DC 20418 (202) 334-3313

Sunburst Communications
1101 Castelton Street
Pleasantville, NY 10570-3498
(800) 628-8897
(914) 747-3310

This free catalog advertises computer software for teaching all subject areas at any grade level. Computer programs for teaching problem solving strategies using such activities as logic puzzles, simulated manufacturing, or building a gear factory are available. Simulated science experiments are described such as keeping outer space creatures alive in the classroom, creating planets, or growing plants under various conditions. The software may be used as problem-centered learning activities or can provide teachers with ideas for lessons.

Tom Snyder Productions
90 Sherman Street
Cambridge, MA 02140
(800) 342-0236

This free catalog describes activity books, laser disk and computer programs, and other tools for teaching any grade level. Problem-solving activities can be found in such activities as mystery-games which use mathematics, videotapes that encourage cooperative learning, and a simulation of a geological expedition. These activities may be used to create problem-centered lessons or to help students search for solutions.

Textbooks and Activity Books

Science Laboratory Activities. (1990). Fort Lauderdale, FL: Broward County Public Schools.
This is a set of activity manuals for grades kindergarten through eight which were developed for the Science is Elementary program in Broward County, Florida. Each manual includes exploratory experiments appropriate for the grade level which correspond with state minimum basic skills. The fourth grade manual, for example, includes problem-centered lessons such as determining the activities of another classroom by looking at its garbage, or exploring static electricity using balloons and cereal.

Serra, M. (1989). *Discovering geometry: An inductive approach.* Berkeley: Key Curriculum Press.
Geometry students can use this textbook to "'create' geometry for themselves as they proceed through the activities and problems." Lessons are designed so that students form and test their own definitions, discover properties of geometric figures, solve logic problems, and develop visualization skills. Group project suggestions include making kaleidoscopes, designing a racetrack, and finding the height of the school building, and each chapter ends with a problem-solving exercise related to living in a lunar colony in the 21st century.

Smith, E., Blackmer, M., & Schlichting, S. (1987). *Super science sourcebook.* Idea Factory, Inc.
This activity book describes a multitude of elementary science activities that can be used to explore concepts in earth, physical, and life sciences. Also included is a section on teaching investigation skills such as observing, inferring, classifying, and graphing. Some reproducible materials are provided for certain lessons. These activities can be used to teach with a problem-centered approach.

U. S. Department of Education. (1991). *Helping your child learn science.* Washington, D. C.: Author.
Designed to provide parents with some simple science activities that can be tried at home; this book could easily be used in an elementary classroom as well. Activities include using soap to power a paper boat, growing mold, and discovering adhesives at home and in nature. Each activity includes a list of suggested materials, and each is followed with questions for children about what they saw or experienced. These activities could introduce a number of problem-centered lessons in the classroom.

Order free from R. Woods, Consumer Information Center, Pueblo, Colorado 81009.

ERIC

Winter, M. J., Lappan, G., Phillips, E., and Fitzgerald, W. (1986). *Spatial visualization.* Menlo Park, CA: Addison-Wesley.

This activity book was developed by the Middle Grades Mathematics Project, which is a curriculum program for grades 5 through 8. The instructional model used by this project is a "launch, explore, and summarize" approach in which the teacher introduces a challenge, students explore solutions using problem-solving strategies, and the whole class discusses their findings. Each lesson provides suggestions on what the teacher can do, say, and expect when encouraging students to discover solutions to problems.

Other Publications

Alabama State Department of Education, Division of Student Instructional Services. *Cooperative learning: Training manual.* Montgomery, AL: Author.
This teacher training manual provides a wealth of information about the theory of cooperative learning, the steps for planning and implementing cooperative lessons, how to teach cooperative skills, different ways to use cooperative learning in the classroom, and how to evaluate cooperative projects. The manual also provides forms and checklists for teachers to use, a glossary of key words, answers to commonly asked questions about cooperative learning, and an extensive bibliography for more information. This manual may be helpful in implementing the small-group portion of a problem-centered lesson.

Biological Sciences Curriculum Study. Implementation guide: Science for life and living: Integrating science, technology, and health.
This implementation guide for the Science for Life and Living program can be a useful resource for systemic change in the teaching of science. It includes suggestions for managing cooperative learning and for implementing assessment changes and staff development programs. The information provided could be used to implement a problem-centered approach in a school.

Available from the National Council of Teachers of Mathematics:

***Curriculum and evaluation standards for school mathematics.* (1989). Reston, VA: NCTM.**
Designed to establish a broad framework which will guide reform in school mathematics, this book contains a vision of what K through 12 mathematics curricula should include in terms of content priority and emphasis. As school staff, school districts, states, and other groups formulate new ideas, they are encouraged to use these standards as criteria.

***Professional standards for teaching mathematics.* (1991). Reston, VA: NCTM.**
This publication is a companion to the *Curriculum and Evaluation Standards for School Mathematics*. It spells out what teachers need to know to meet the new goals for mathematics education, and how teaching should be evaluated for the purpose of improvement. The standards rest on the following two assumptions: 1) teachers are key figures in changing the ways in which mathematics is taught and learned in schools; and 2) such changes require that teachers have long-term support and adequate resources.

Reports are available by mailing $25.00 per report, or $42.50 for the set, to the National Council of Teachers of Mathematics, 1906 Association Drive, Reston, VA 22091, (703) 620-9840.

Teaching Thinking and Problem Solving

This is a newsletter published by Research for Better Schools which is "devoted to theory, research, and practice related to thinking skills." Feature articles on such topics as how to implement a thinking-skills program into the curriculum are included; the newsletter also provides a calendar of related conference events, and book reviews on thinking and problem solving in education.

Subscriptions to this newletter are available for $28.00 per year (6 issues) from LEA, 365 Broadway, Hillsdale, NJ 07642 (201) 666-4110

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APPENDIX

LEARNING STYLES INVENTORIES

The following exercises can be used to determine the learning styles of a class of students. Information about each student's style of learning can be used to group students more effectively, help tne teacher choose appropriate instructional techniques, and assist in the design of effective problem-centered lessons. The two inventories are based on the theory that students prefer to learn through one of three approaches:

visual (prefer to read or look at films or pictures),
auditory (prefer lectures, audiotapes, and recitation), or
kinesthetic (prefer writing and hands-on activities).

The following inventory is from **Baxter, W.** ***Test for three types of learners.***

To give this test, you need the following:

1. A group of not more than 15 students, as it is difficult to observe more than that number of students at one time.

2. A list of the students' names, beside which you can record their reactions.

Reactions to watch for:

VISUAL LEARNERS will usually close their eyes or look at the ceiling as they try to recall a visual picture.

AUDITORY LEARNERS will move their lips or whisper as they try to memorize.

KINESTHETIC LEARNERS will use their fingers to count off items or write in the air.

The test consists of pretending that the students are going to the store to buy a few things. First, you will WRITE the list on the board, allowing the students to watch you, but they must not copy it. Next, you will give them a list ORALLY. You will not write it and neither must they. Then, you will dictate the list to them ORALLY and they will write it down.

After each presentation, you will ask your students to repeat the list to you if they wish. Responses to your request should be voluntary and the list does not have to be given back in order. The following presentations are suggested.

First Presentation

LIST: Toothpaste, Soap, Kleenex, Comb, Stationary

1. Write the list on the board while the students are watching you. Do not let them write.

2. Allow students to view the list for approximately one minute. Observe their reactions. As you notice a student's reaction, mark V, A, or K after his/her name.

3. Erase the list.

4. Ask "Who would like to repeat the items to me?"

5. Observe that the visual learners will wave their hands enthusiastically.

6. Call on them to recite orally, one at a time. (Note that after a few students have recited, a few more timid hands will go up. These usually are auditory learners who have learned the list, not from seeing it, but from hearing the other students say the items.)

Second Presentation

LIST: Folded Paper, Talcum Powder, Nail File, Cough Drops, Shaving Cream

1. Dictate the list orally (no writing by either teacher or students). Repeat the dictation a second time, pausing for a moment after each item.

2. Observe the students' reactions. Make the appropriate notation of V, A, or K after the students' names.

3. Ask "Who would like to repeat the list?

4. The auditory learners will be the most eager to respond, although other students will try to repeat the items you have dictated.

Third Presentation

LIST: Lipstick, Band Aids, Razor Blades, Cough Syrup, Fountain Pen

1. Tell the students to have pencil and paper ready to write the list as you dictate it orally. Tell them you will not count spelling, or you can spell the words as you dictate.

2. After you have finished dictating the list, tell the students to rewrite the list. They may look at the one that they have written from your dictation.

3. When they have finished rewriting the list, tell them to turn the paper over and write the list from memory.

4. After they have finished, check to see which students have been able to repeat the list wholly or in part.

5. Notice if students who were unsuccessful in either the first or second presentation of the test are frequently the first ones finished in this presentation. These are the kinesthetic learners.

After you have finished these three presentations, repeat the same procedures using numbers instead of words. Use three, four-digit numbers in each list.

Learning Channels Inventory (for older students)

Ask your students to answer "yes" or "no" to each of the following questions:

1. Do you prefer to read about something first when learning it?
2. Do you say the words to yourself when reading a book or questions on a test?
3. Do you prefer to work with "the real thing" while learning?
4. When you learn something new, do you prefer to learn by seeing a filmstrip or film?
5. Do you remember things best by closing your eyes and seeing them in your mind?
6. Do you prefer to draw, paint, or trace things that you are learning?
7. Do you remember things best by hearing them first?
8. Do you learn by listening to tapes, the radio, or records?
9. If you were learning measurements in math, would you prefer to learn them by doing an activity like cooking or carpentry?

When you study something to remember it, do you prefer to

10. write it down?
11. say it to yourself?
12. read it?

When you are learning something new and really want to understand it, how do you prefer to learn it?

13. By playing a game?
14. Listening to the teacher explain it?
15. Seeing a movie about it?

Students who are visual learners will have answered yes to most of the following numbers: 1, 4, 5, 12, and 15.
Students who are auditory learners will have answered yes to most of the following numbers: 2, 7, 8, 11, and 14.
Students who are kinesthetic learners will have answered yes to most of the following numbers: 3, 6, 9, 10, 13.

To find out more about learning styles, the following publication may be helpful:

American Association of School Administrators. (1991). *Learning styles: Putting research and common sense into practice.* Arlington, VA: Author.

This book summarizes research on learning styles, reviews how schools are preparing staff to integrate knowledge about learning styles, and discusses how research and common sense are actually being applied in the classroom. It provides descriptions of exemplary school programs that are sensitive to learning styles, discusses strategies for implementation, and answers teachers' questions about the use of learning styles in the classroom.

SUBJECT INDEX

Almy, M., & Ginishi, C. (1979). *Ways of studying children: An observational manual for the early childhood teacher.* New York: Teachers College Press.

American Association for the Advancement of Science. (1989). *Project 2061: Science for all Americans.* Washington, D. C.: Author.

Archbald, D. A., & Newmann, F. M. (1988). *Beyond standardized testing: Assessing authentic academic achievement in the secondary school.* Reston, VA: National Association of Secondary School Principals.

Atkinson, J. W. (Ed.). (1958). *Motives in fantasy, action, and society.* Princeton, NJ: Van Nostrand.

Beyer, B. K. (1987). *Practical strategies for the teaching of thinking.* Boston: Allyn & Bacon.

Brilhart, J. K. (1986). *Effective group discussion.* Dubuque, IA: Wm. C. Brown.

Carnegie Foundation. (1983). *High school: An agenda for action.* New York: Author.

Champagne, A. B., Lovitts, B. E., & Calinger, B. J. (Eds.). (1990). *This year in school science 1990: Assessment in the service of instruction.* Washington, D. C.: American Association for the Advancement of Science.

Cheves, D., & Parks, T. (1984). Making problem solving real. *Educational Leadership, 41*(4), 54-57.

Cobb, P., & Wheatley, G. (1988). *Children's initial understanding of ten. Focus on Learning Problems in Mathematics, 10*(3), 1-28.

Cobb, P., Wood, T., Yackel, E., Nicholls, J., Wheatley, G., Trigatti, B., & Perlwitz, M. (1991). *Assessment of a problem-centered second-grade mathematics project. Journal for Research in Mathematics Education, 22*(1), 3-29.

Costa, A. L., & Lowery, L. F. (1989). *Techniques for teaching thinking.* Pacific Grove, CA: Midwest Publications.

Davidson, N. (1985). Small group learning and teaching in mathematics: A selective review of the research. In R. Slavin, S. Sharan, K. Spencer, R. Hertz-Lazarowitz, C. Webb, & R. Schmuck (Eds.), *Learning to cooperate, cooperating to learn* (pp. 211-230). New York: Plenum Press.

Gagne, R. M. (1980). Learnable aspects of problem solving. *Educational Psychologist, 15*(2), 84-92.

Gardner, H. (1983). *Frames of mind: The theory of multiple intelligences.* New York: Basic Books.

Ivany, J. W. G., & Wassermann, S. (1988). *Teaching elementary science: Who's afraid of spiders?* New York: Harper & Row.

Johnson, R. T., & Johnson, D. W. (1989). Cooperative learning and the gifted science student. In P. F. Brandwein & A. H. Passow (Eds.), *Gifted young in science: Potential through performance* (pp. 321-329). Washington, D. C.: National Science Teachers Association.

Johnson, D. W., Johnson, R. T., Holubec, E. J., & Roy, P. (1984). *Circles of learning: Cooperation in the classroom.* Association for Supervision and Curriculum Development.

Johnson, R. T., Johnson, D. W., & Maruyama, G. (1983). Interdependence and interpersonal attraction among heterogeneous and homogeneous individuals: A theoretical formulation and a meta-analysis of the research. *Review of Educational Research, 53*, 5-54.

Kamii, C., & Lewis, B. A. (1990). Research into practice: Constructivism and first grade arithmetic. *Arithmetic Teacher, 38*(1), 36-37.

Knight, L. H., Altman, L. T., Carpenter, J. R., & Rachelson, S. (1990). *BSAP science: Teaching through inquiry.* Columbia, SC: South Carolina Department of Education.

Lawrenz, F. (1991). Research matters to the science teacher: Authentic assessment. *NARST News, 33*(2). Manhattan, KS: Kansas State University.

Loucks-Horsley, S., Kapitan, R., Carlson, M. A., Kuerbis, P. J., Clark, R. C., Melle, G. M., Sachse, T. P., & Walton, E. (1990). *Elementary school science for the '90s.* Washington, D. C.: Association for Supervision and Curriculum Development.

Math skills don't add up. (1991, June). *Tallahassee Democrat.*

McKnight, B. J. (1989). Problem solving in elementary school science. In D. Gabel (Ed.), *What research says to the science teacher: Problem solving* (Vol. 5) (pp. 7-11). Washington, D. C.: National Science Teachers Association.

Mullis, I. V. S., Dossey, J. A., Owen, E. H., & Phillips, G. W. (1991). *The state of mathematics achievement: Executive Summary. NAEP's 1990 assessment of the nation and the trial assessment of the states.* Washington, D. C.: National Center for Education Statistics.

National Council of Supervisors of Mathematics. (1977). Position paper on basic mathematical skills. Washington, D. C.: National Institute of Education.

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

National Research Council. (1989). *Everybody counts: A report to the nation on the future of mathematics education.* Washington, D. C.: National Academy Press.

Nicholls, J. (1983). Conceptions of ability and achievement motivation: A theory and its implications for education. In S. G. Paris, G. M. Olsen, & W. H. Stevenson (Eds.), *Learning and motivation in the classroom* (pp. 211-237). Hillsdale, NJ: Erlbaum.

Pollak, H. O. (1978). On mathematics application and real problem solving. *School Science and Mathematics, 78*(3), 232-239.

Project WILD: Elementary Activity Guide. (1983). Boulder: Western Regional Environmental Education Council.

Raizen, S., Baron, J., Champagne, A., Haertel, E., Mullis, I., & Oakes, J. (1989). *Assessment in elementary school science.* Washington, D. C.: National Center for Improving Science Education.

Resnick, L. B. (1987). *Education and learning to think.* Washington, D. C.: National Academy Press.

Robblee, K. M. (1991). Cooperative chemistry. *The Science Teacher, 58*(1), 20-23.

Serra, M. (1989). *Discovering geometry: An inductive approach.* Berkeley: Key Curriculum Press.

Squaring the root. (1991). *High Strides, 3*(5).

Slavin, R. E. (1985). An introduction to cooperative learning research. In R. Slavin, S. Sharan, K. Spencer, R. Hertz-Lazarowitz, C. Webb, and R. Schmuck (Eds.), *Learning to cooperate, cooperating to learn* (pp. 5-15). New York: Plenum Press.

Slavin, R. E. (1988). *Educational psychology: Theory into practice.* Englewood Cliffs, NJ: Prentice Hall.

Toch, T. (1991). *In the name of excellence: The struggle to reform the nation's schools, why it's failing, and what should be done.* New York: Oxford University.

Webb, N. (1985). Verbal interaction and learning in peer-directed groups. *Theory Into Practice, 24*, 32-39.

Wheatley, G. H. (1984). Problem solving makes math scores soar. *Educational Leadership, 41*(4), 52-53.

Wheatley, G. H. (1991). Constructivist perspectives on science and mathematics learning. *Science Education, 75*(1), 9-21.

Yackel, E., Cobb, P., Wood, T., Wheatley, G., & Merkel, G. (1990). The importance of social interaction in children's construction of mathematical knowledge. In T. J. Cooney & C. R. Hirsch (Eds.), *Teaching and learning mathematics in the 1990s* (pp. 12-21). Reston, VA: National Council of Teachers of Mathematics.

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