12

Teaching by Fostering Problem-Solving Strategies

Chapter Outline

Can Problem-Solving Skills Be Taught?

What Makes an Effective Problem-Solving Program?

Productive Thinking Program

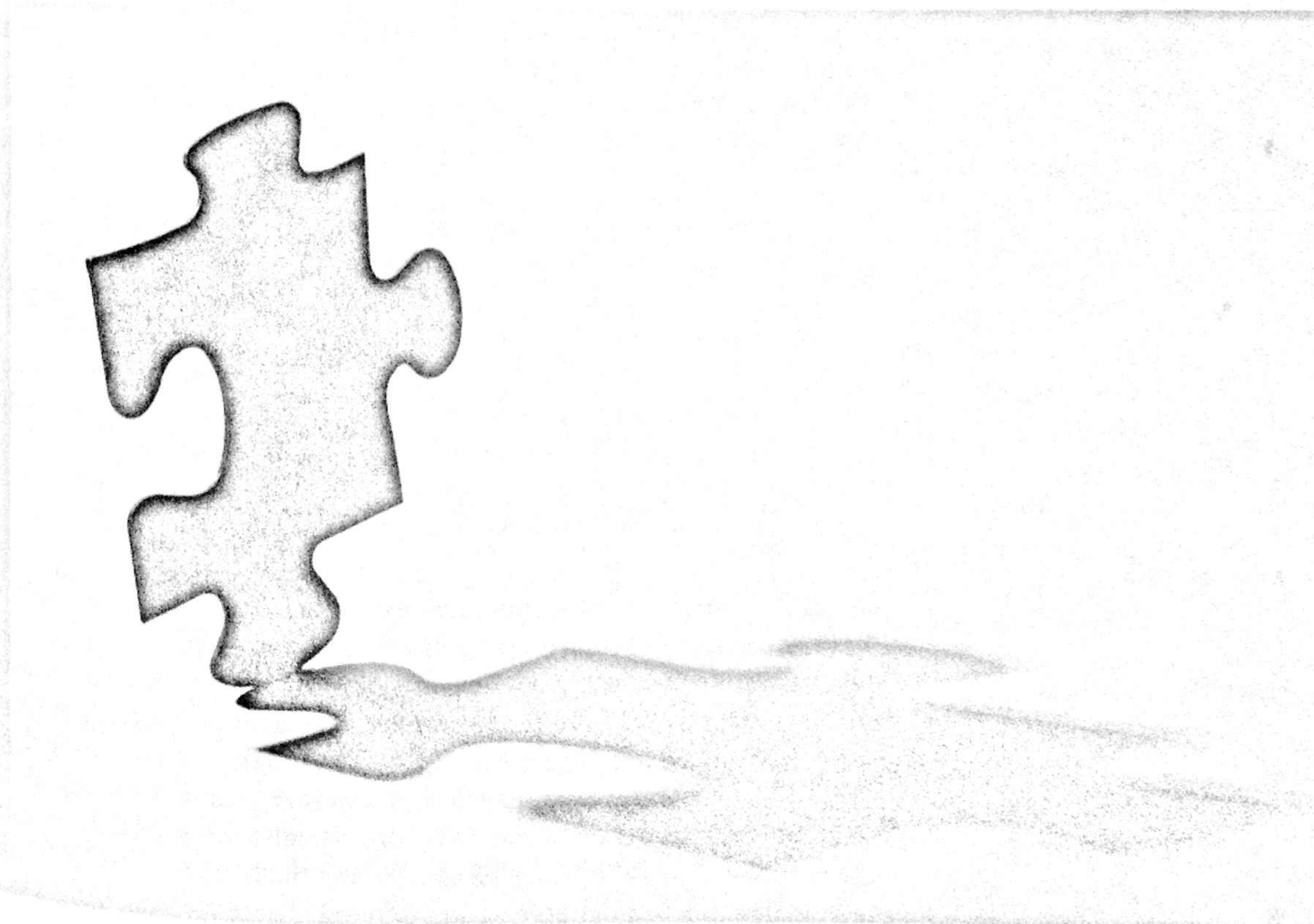
Instrumental Enrichment

Project Intelligence

The Case for Improving Problem-Solving Skills Instruction

Chapter Summary

This chapter examines whether students can be taught strategies that help them become more effective problem solvers. I begin by establishing four criteria for effective problem-solving programs. Then, I examine three school-based projects aimed at boosting students' problem-solving skills. The research encourages continuing work on identifying the teachable aspects of problem-solving transfer.



Can Problem-Solving Skills Be Taught?

An important goal of most educational institutions is the improvement of the human mind. But what exactly does it mean to improve someone's mind? One interpretation is that students should become more effective problem solvers: We want students, when faced with a new problem, to be able to figure out an appropriate solution. For example, after studying basic arithmetic, a fourth-grade student is asked the following (Davis & Maher, 1997, p. 106):

> How many different pizzas can be made if every pizza has cheese, but to this you can add whichever of the following toppings you wish and in any combination you wish:
>
> green peppers
> sausage
> mushrooms
> pepperoni

If you have not yet learned the formula for computing the number of combinations, this problem requires creative problem solving.

As another example, after studying a science lesson on heat and temperature, an eighth-grade student is given the following problem (adapted from Linn & Hsi, 2000, p. 143):

> Which container would be best for keeping soup hot—a large bowl or a small bowl?

Answering this question requires creatively using what you know about the concept of heat flow and the insulating properties of various materials.

As a final example, after studying international diplomacy involving social, political, and economic issues, high school students were asked to grapple with the following problem:

> In 1492, there was a proposal that all Jews be expelled from Spain. The two monarchs, Ferdinand and Isabella, who sent Columbus on his voyage, were very strong Catholics. Spain was very divided at the time. There were different ethnic groups, different political groups, and different religions in the country. As a way of unifying the country, it was proposed that Spain tell all the Jews they had four months to either convert to Catholicism or leave Spain for good. There was a Jewish man named Abrabanel who was an advisor to the King and Queen. He was supposed to advise them on what to do about this proposal to expel the Jews from Spain. Imagine that you are Abrabanel. Think about what you would have done if you had been asked for advice. (Torney-Punta, 1994, p. 111)

In solving this problem, students must use what they know about religious minorities as well as the social, political, and economic climate of the period.

Being able to solve problems such as these can be taken as an indication of an educated mind. In solving these problems the student needs to do more than simply remember an answer; the student needs to create a novel solution. The educational goal of improving students' minds prompts the question of whether problem-solving skills can be taught. This chapter explores the question, "Is it possible to teach our students to become better problem solvers?" Most of the chapters in this book examine ways of teaching that promote transfer, but this chapter takes a more direct approach by asking how we can

teach problem-solving skills. In the next section, I establish four criteria for teaching problem-solving strategies.

What Makes an Effective Problem-Solving Program?

Consider the following scenario. The president of your country has announced a national goal of ensuring that all children who enter school as kindergartners are intellectually ready to learn. Your country stands ready to spend billions of dollars over the ensuing years to increase the intellectual ability of needy preschoolers. Suppose you are appointed to a government board charged with designing an educational program to improve children's intellectual ability. What would you do?

As you probably suspect, this scenario is not made up. In 1965, the United States initiated a national program called Head Start, which sought to improve the intellectual functioning of preschool children living in poverty. For the next 35 years, Head Start became "the most important social and educational experiment of the second half of the twentieth century" (Zigler & Muenchow, 1992, p. 2). One of the founding goals of Head Start was to "improve the child's mental processes" (p. 20), and increases in intelligence test scores became the main objective for demonstrating success. Today, Head Start remains an important national commitment, but one that could benefit from research and theory in meaningful learning (Caruso, Taylor, & Detterman, 1982; Zigler & Muenchow, 1992). Throughout its history and continuing into the 21st century, the goal remains the same: "All children in America will start school ready to learn" (Zigler & Muenchow, 1992, p. 211). If you were in charge, what would you do to "improve intellectual functioning" (Caruso et al., 1982, p. 51)?

First, you might wonder whether intellectual functioning (as measured by IQ tests) can actually be improved. Some promising news comes from Flynn (1998), who has been tracking IQ scores in 20 industrialized countries around the world. Flynn's major finding, called the *Flynn effect*, is that "IQ scores have been rising for most of the 20th century in every country for which pertinent data are available" (Martinez, 2000, p. 90). For example, from 1918 to 1995, the average IQ score in the United States increased by 25 points—almost two standard deviations. Flynn concludes that "somewhere out there environmental variables of enormous potency are creating IQ differences" (p. 53). Martinez provides additional data showing that educational experience can have a marked effect on people's IQ scores, and he therefore sees education as a means of cultivating human intelligence.

If you wished to design an instructional program aimed specifically at improving students' intellectual ability, you would need to make some decisions about what to teach, where to teach, how to teach, and when to teach. These four issues are summarized in Figure 12–1. To help you in your decision process, let's begin with some commonsense principles for how to teach students to be better problem solvers (Mayer, 1997, p. 480). Please rate your degree of agreement with each statement by circling a number from 1 (strongly disagree) to 7 (strongly agree).

1. The ability to solve problems depends on improving the human mind. The mind is like a mental muscle that needs to be strengthened.
   (disagree) 1 2 3 4 5 6 7 (agree)

FIGURE 12–1
Four issues for thinking skills programs

Issue	Alternatives
1. What to teach	Thinking as a single intellectual ability versus thinking as a collection of smaller component skills.
2. Where to teach	In general, domain-independent courses or within existing, specific subject areas.
3. How to teach	Focus on product through rewarding correct answers versus focus on processes that the student learns to model.
4. When to teach	After basic skills are mastered versus before.

Source: Adapted from Mayer, R. E. (1997), Incorporating problem solving into secondary school curricula, In G. D. Phye (Ed.), Handbook of academic learning (pp. 474–492), San Diego, CA: Academic Press, Copyright © 1997, with permission from Elsevier.

2. Like any other academic subject, problem-solving courses should be required for all students. The general skills students learn in a problem-solving course will be useful in their problem solving in other academic subjects ranging from language arts to mathematics to science to history.
   (disagree) 1 2 3 4 5 6 7 (agree)
3. Like the training of any skill, the best way to learn how to be a better problem solver is through regular mental exercises. Students need practice in giving the right answer to exercise problems.
   (disagree) 1 2 3 4 5 6 7 (agree)
4. Students cannot learn about higher-order thinking skills until they have mastered lower-level basic skills. For example, students cannot learn how to design compositions until they know how to spell and punctuate, and they cannot solve complex math word problems until they have mastered basic arithmetic procedures.
   (disagree) 1 2 3 4 5 6 7 (agree)

These principles seem to square with conventional wisdom and provide a prescription for how to improve students' intellectual ability. Regrettably, though, they conflict with relevant research and theory (Mayer, 1997), so let's review each one in more detail.

WHAT TO TEACH: ONE ABILITY VERSUS MANY COGNITIVE SKILLS

Looking for Intelligence as One or Many As reflected in the first item in my survey, the first major issue concerns whether humans possess a single intellectual ability (single intelligence theory) or many smaller skills that together account for a person's intellectual ability (cognitive skills theory). One of the earliest battles between these two views can be seen in early conceptions of intelligence testing proposed by Galton and by Binet. In trying to measure intellectual ability, Galton (1883) and Binet (1911/1962) had to consider whether intelligence was a single ability or a collection of smaller skills.

For example, suppose you wish to measure human intellectual ability and you believe that problem solving depends on a single ability—such as how fast your brain worked or how sensitive your mind was to small differences. To measure speed of mental functioning

you could test people on reaction time tasks, such as pressing a button as soon as a light appeared. To measure sensitivity, you could ask people to hold two weights and decide which was heavier. Galton (1883) was the first to propose that intellectual functioning depended on a single mental ability (which he called the *human faculty*) and to devise clever ways to measure it. Yet subsequent research showed that his tests failed to correlate with any practical measures of intellectual ability such as school grades (Sternberg, 1990).

In contrast, suppose that you are asked to devise a test that would predict school success so that students with potential learning problems could be given special assistance. If you see intellectual ability as reflected in possessing a collection of smaller, component skills, the test should focus on many small skills. In response to just such a call from the French Ministry of Education, Binet (1911/1962) was the first to propose that intellectual ability—at least the ability to learn—depended on possessing many smaller skills and to show how such skills can be measured. For example, based on his studies of individual differences among French school students, Binet offered one of the first arguments for the cognitive skills theory:

> Intelligence is not a simple indivisible function with a particular essence of its own . . . but, it is formed by the combination of all the minor functions . . . all of which have proved to be plastic and subject to increase. With practice, enthusiasm, and especially with method, one can succeed in increasing one's attention, memory, and judgment, and in becoming literally more intelligent than before, and this process will go on until one reaches one's limit (p. 150).

Binet even devised a series of exercises that he called mental orthopedics: "In the same way that physical orthopedics straightens a crooked spine, mental orthopedics strengthens, cultivates, and fortifies attention, memory, perception, judgment, and will" (p. 150). Unlike Galton's tests, Binet's tests did correlate—although not perfectly—with school success.

If you accept Binet's assertions that intellectual performance is based on small intellectual skills that can be identified and taught, the next task becomes one of trying to better describe these skills. In his theory of multiple intelligences, for example, Gardner (1983, 1999) proposed a collection of intellectual skills, including linguistic intelligence, musical intelligence, logical-mathematical intelligence, spatial intelligence, bodily-kinesthetic intelligence, and personal intelligence. Suppose we wish to dig deeper and ask, "Can intellectual performance within any of these domains be analyzed into component processes?" Mayer (1992b) has shown that there are two major kinds of cognitive processing:

1. Representational processes—for building a coherent and useful internal representation of the problem.
2. Solution processes—for creating, carrying out, and monitoring a plan.

The specific representational and solution processes may depend on the specific intellectual task.

Using a cognitive approach, problem-solving courses can teach strategies for representing problems and searching for solutions. Some suggestions for representational strategies are to relate the problem to a previous problem, restate the problem in other words, and draw a picture or diagram. Some suggestions for searching include working from the goal to the givens, breaking the problem into subgoals, and only making moves that solve a particular subproblem.

Polya's Teaching of Problem Solving Polya's (1945, 1965) program for teaching problem solving has influenced the development of many more recent programs. For example, Polya's (1965) observations of high school mathematics students led him to emphasize techniques for representing and planning problem solutions:

> I wish to call heuristics . . . the study of the means and methods of problem solving . . . I am trying, by all means at my disposal, to entice the reader to do problems and to think about the means and methods he uses in doing them. . . . What is presented here are not merely solutions but case histories of solutions. Such a case history describes the sequence of essential steps by which the solution has been eventually discovered, and tries to disclose the motives and attitudes prompting these steps. The aim . . . is to suggest some general advice or pattern which may guide the reader in similar situations (p. 8).

In short, Polya argued that students should be asked to solve problems and to observe others solve problems, with the emphasis on the process of problem solving rather than on the final answer. Some of the heuristics suggested by Polya are to find a related problem that you can solve, break down the problem into smaller parts, and draw a picture of the problem.

In his classic little book *How to Solve It*, Polya (1945) offered the following four-step general procedure for solving problems, especially mathematics problems.

1. Understand the problem. The problem solver must see what is given, what is unknown, and what operations are allowed. In short, the problem solver must represent the problem.
2. Devise a plan. The problem solver must determine a general course of attack, such as restating the problem so that it is more like a familiar problem.
3. Carry out the plan. The problem solver must carry out the computations and other needed operations.
4. Look back. The problem solver looks over the processes he or she went through, trying to see how this experience can be helpful in solving other problems.

Figure 12–2 provides an example of how these four steps can be applied to the problem of finding the volume of the frustum of a right pyramid.

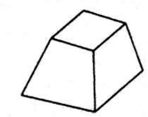
Although Polya's ideas have been highly influential, especially among some mathematics educators, you might wonder whether there is any evidence that problem-solving heuristics (or skills) can be taught. To help answer that question, Schoenfeld (1979) taught heuristics for mathematical problem solving to college students. The trained group was given a 5-problem pretest, training on how to solve 20 example problems, and then a 5-problem posttest. The trained group was given a list and description of heuristics, such as partially shown in Figure 12–3. Then, in each session all the problems were solvable by the same heuristic, and subjects were explicitly told which heuristic to apply to the problems. The control group received the same pretest, the same 20 example problems, and the same posttest as the trained group. However, the control group was not given a list of heuristics, and the problems in each session were not all solvable by the same heuristic.

The results showed that the trained group increased from an average score of 20% correct on the pretest to 65% on the posttest, whereas the control group averaged 25% correct on both tests. Although the sample size was small in this study, the results suggest that it is

FIGURE 12–2
Polya's four steps in problem solving

PROBLEM

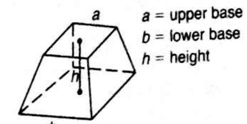
Find the volume of the frustum of a right pyramid with a square base, given the height of the frustum, the length of a side of its upper base, and the length of a side of its lower base.



STEP 1: Understand the Problem.

What Is Given?
The height, the length of the upper base, the length of the lower base.

What Is Unknown?
The volume of the frustum.

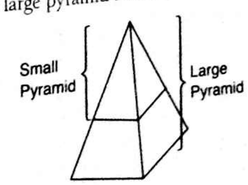


STEP 2: Devise a Plan.

Is There a Related Problem?
The volume of a right pyramid can be obtained as follows:

$$\text{Volume} = \frac{(\text{base})^2 \times (\text{height})}{3}$$

Can You Restate the Unknown?
Find the volume of the large pyramid minus the volume of the small pyramid.



STEP 3: Carry Out the Plan.

Calculate volume of large pyramid.
Calculate volume of small pyramid.
Subtract the second from the first.

STEP 4: Look Back.

This technique can be applied to other problems, such as "Find the area of a donut, given the radius to the inside and outside."

Adapted from Polya (1968).

RE 12-3
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enfeld

1. Draw a diagram if at all possible.
2. If there is an integer parameter, look for an inductive argument.
3. Consider arguing by *contrapositive* or *contradiction*.
   Contrapositive: Instead of proving the statement "If X is true, then Y is true," you can prove the equivalent statement "If Y is false, then X must be false."
   Contradiction: Assume, for the sake of argument, that the statement you would like to prove is false. Using this assumption, go on to prove either that one of the given conditions in the problem is false, that something you know to be true is false, or that what you wish to prove is true. If you can do any of these, you have proved what you want.
4. Consider a similar problem with fewer variables.
5. Try to establish subgoals.

Source: Adapted from Schoenfeld, A. H. (1979). Explicit heuristic training as a variable in problem solving performance. Journal for Research in Mathematics Education, 10, 173–187.

possible to identify teachable aspects of problem solving—in this case, some Polya-like heuristics within the domain of mathematics.

Criterion 1: Teach Component Skills With respect to the issue of what to teach, I interpret the current research base to favor teaching of component skills rather than teaching of a single monolithic ability. For example, problem solving can be broken down into individual representational or solution strategies that can be taught. Training in problem solving involves teaching students the component processes in problem solving. The particular list of problem-solving strategies (or skills) tends to vary depending on the subject matter of the problems to be solved. The implications for the design of a problem-solving program are that the content of the course should be definable skills for representing and solving problems, including skills for planning and monitoring one's plans. Subsequent sections of this chapter explore some of the specific content of problem-solving programs.

WHERE SHOULD PROBLEM-SOLVING STRATEGIES BE TAUGHT?

Looking for Intelligence as Specific or General As reflected in the second item in my survey, the second issue concerns whether problem-solving strategies are general or specific. The instructional implication concerns whether problem solving should be taught as a separate general course or within specific subject areas. Thus, once we have pinpointed important cognitive skills—such as how to represent a problem or how to devise a solution plan—should we teach these as general or specific skills? Should we expect students to learn general problem-solving strategies that can be applied to a wide variety of tasks, or should we expect students to perform well mainly on applying specific strategies to problems like those given in training? For example, suppose that your goal is to teach students a planning strategy such as how to break a problem into parts. Should you teach this as a general skill in a separate lesson on general problem solving, or

should you teach how to break down a math problem into parts (during mathematics instruction), how to break a composition into its parts (during language instruction), how to analyze a historical problem (during history instruction), and so on?

Early research on intelligence testing addressed the issue of whether intellectual ability is general or specific. Consider the following situation: You give a large battery of cognitive tests to a large group of people. If intelligence is general, tests measuring the same skill—such as memory or learning—should correlate with one another: That is, people who score high on one memory test should tend to score high on other memory tests, people who score high on one learning test should score high on other learning tests, and so on. Spearman (1927) found some evidence that all the tests correlated with one another, so he took this as evidence for general aspects of intelligence (which he called g-factors). He also found that certain clusters of tests correlated particularly well, so he took this as evidence for specific aspects of intelligence (which he called s-factors). Later, Thurstone (1938) repeated this kind of study using more sophisticated statistical analyses. This time, he found evidence for only seven primary mental abilities. For example, tests of mathematical thinking measured something different from tests of verbal thinking. These results suggest that intellectual ability may be domain specific—that is, cognitive skills that are useful in one subject area (such as being able to plan an essay) may not have much in common with cognitive skills used in an unrelated subject area (such as being able to plan a solution to a math word problem).

What Experts Know What does it take to be an expert in some field—general mental ability or specific cognitive skills? This question was addressed in a classic study by de Groot (1965) in which he compared the cognitive functioning of chess experts and novices. If chess expertise is a general skill, you can expect experts to perform better than novices on all kinds of memory tests. In contrast, de Groot found that experts and novices performed at similar levels on standard memory tests; however, experts outperformed novices on remembering the position of chess pieces on the board of an actual game. In short, experts performed well on domain-specific tests of memory—remembering chess positions from real games—but not on domain-general tests of memory, such as remembering a list of words. In fact, novices and experts even performed the same on remembering the position of chess pieces that had been placed randomly on the board (Chase & Simon, 1973). Apparently, experts developed skill in how to mentally group pieces into meaningful clusters, effectively increasing their memory for chess pieces. These results suggest that expertise is highly domain specific; that is, the cognitive skills needed for cognition in one domain (such as chess) are not related to other domains. Thorndike's research on the problems with general transfer, discussed in Chapter 1, tells a similar story.

Criterion 2: Teach Within Specific Domains Overall, the question of where to teach is still somewhat controversial, but I interpret the research base to favor embedding instruction within specific domains. Research on intelligence testing, on expertise, and on cross-discipline transfer all suggest that it is best to have students learn on problem-solving tasks that are similar to the tasks they will be expected to perform later. There is no convincing evidence that learning to solve problems in one subject area, such as solving logic problems, has a strong effect on solving problems in another subject area, such as writing persuasive essays (Mayer, 1992b).

HOW SHOULD PROBLEM-SOLVING SKILLS BE TAUGHT?

Process Versus Product The third question in the survey you took at the beginning of this chapter concerns the issue of how to teach—by focusing on giving students practice in producing the right answer or in helping students understand the process of successful problem solving. Once a set of problem-solving skills has been identified, the next issue concerns how to teach these skills to students. "We should be teaching students how to think; instead we are primarily teaching them what to think." So asserts Lochhead (1979, p. 1) in the introduction to the book he wrote with John Clement, *Cognitive Process Instruction*. What Lochhead and others are saying is that teachers are emphasizing *product* (i.e., getting the right answer) instead of *process* (i.e., how to go about solving problems).

Bloom and Broder's Teaching of Problem Solving In one of the first experimental research studies on teaching of problem solving, Bloom and Broder (1950) carried out a program to improve the problem-solving performance of college students at the University of Chicago. The university required that students pass a series of comprehensive examinations in subject matter areas. As you might expect, some students (called "model students") performed quite well on the exams. In contrast, other students (called "remedial students") who were just as motivated, studied just as hard, and scored just as high in scholastic aptitude as the model students were unable to pass the exams. Although the model and remedial students seemed equivalent in ability, knowledge, and motivation, the remedial students apparently lacked skills necessary to answer the questions. Thus, Bloom and Broder sought to develop a training program to help the remedial students think like the model students for exam questions.

In determining what to teach, Bloom and Broder (1950) distinguished between

Product of problem solving—whether the student produced the correct answer, and
Process of problem solving—the thought process that a person engages in.

Figure 12–4 shows an economics exam problem and the answers given by three students. As you can see, although the students generated the same final answer, their descriptions of how they generated the answer are quite different. Bloom and Broder decided that the training program for remedial students should focus on the teaching of useful problem-solving strategies rather than on reinforcing students for emitting correct answers.

In determining how to teach, Bloom and Broder (1950) decided to let remedial students compare their solution strategies with those used by the model students. Using a thinking-aloud procedure, remedial students were asked to describe their thought process for a problem, and model students were asked to describe their thought process for the same problem. Then the remedial students were asked to find the differences between how they solved the problem and how the model students solved the problem. For example, Figure 12–5 shows a list of differences that remedial students found between their strategies and those of model students. This model-based training is similar in some ways to the cognitive apprenticeship approach explored in Chapter 13.

In a typical experiment, remedial students were given 10 to 12 training sessions in which they compared their solution strategies to those of models. Students who were trained tended to score about 0.5 to 0.7 grade points higher on the exam and expressed more self-confidence than students of equivalent ability and background who were not given training. Thus, Bloom and Broder (1950) were able to influence problem-solving

FIGURE 12–4
How three students solved the inflation problem

PROBLEM

Some economists feel that there is danger of an extreme inflationary boom after the war. It is the opinion of such economists that the government should control the boom in order to prevent a depression such as the one following the stock-market crash of 1929.

Determine whether each of the following specific suggestions would be *consistent* with the policy of controlling the boom or is directly *inconsistent* with the policy.

26. Lower the reserve that banks are required to hold against deposits.
27. Reduce taxes considerably.
28. Encourage the federal reserve banks to buy securities in the open market.

MARY'S ANSWER

Mary W. (Score 2): (Read the statements and the directions.)
(Read item 26.) "Look down to see what I'm supposed to do."
(Reread the statements and the directions.) "Not quite sure what I'm doing." (Reread the statements and the directions for the third time.)
(Reread item 26.) "Not sure of this, so on to second one."
(Read item 27.) "Say inconsistent, because if there is inflationary boom, if people make more money, taxes have to keep up with it to take away the money so they can't spend it."
(Read item 28.) "Trying to figure out what bearing that had exactly."
(Reread item 26.) "I'm a time waster; say 26 would be consistent—no, that I know, banks have reserve—idea is to get people to deposit as much as possible—not answer 28."
(Reread item 28.) "Say inconsistent; I feel it is."
Diagnosis: unsystematic, jumps around, uses "feeling" rather than "reasoning," not confident.

JAMES'S ANSWER

James S. (Score 2): (Read the statements.) "In other words, the OPA and such."
(Read the directions.) "Take for granted they're going to control the boom."
(Read item 26. Reread item 26.) "That would be inconsistent."
(Read item 27.) "That would be inconsistent, because you can't have too great a boom as long as you have taxes, at least in my interpretation of boom—although if taxes go up, prices go up—no, I'll stick to my answer."
(Read item 28.) "Consistent—however, I think I need more subject-matter background to tell how I thought it out—more of a guess—don't think inconsistent, so put consistent."
Diagnosis: trasnslates problem into something more familiar (OPA), lacks subject matter knowledge, guesses.

(continued)

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DORA'S ANSWER

Dora Z. (*Score 2*): (Read the statement and the directions—emphasizing the key words.)

(Read item 26.) "Lower the reserve, raise the amount of money in circulation—if you raise the money in circulation—inconsistent. By raising the money in circulation you don't control a boom."

(Read item 27.) "Also inconsistent for the same reason."

(Read item 28.) "Open market—think what the open market is. This would take money out of circulation, therefore would be consistent."

Diagnosis: focused on key ideas, reduced three items to a single problem, attempted to determine how money supply is affected by each item, attacks problem on basis of single rule or principle, higher order problem solving.

Source: From Bloom, B. S., & Broder, L. J. (1950). Problem-solving processes of college students: An exploratory investigation. *Chicago: University of Chicago Press. Copyright © 1950.*

performance in subject areas by focusing on process rather than product and by giving students practice in comparing their strategies to those of models.

Criterion 3: Focus on the Problem-Solving Process In summary, research suggests that the method for teaching problem solving should focus on modeling of the steps in the problem-solving *process* rather than solely on the *product* of problem solving. In particular, students need practice in relating their own problem-solving processes to those of models. This modeling technique has become the basis for many of the problem-solving programs discussed in subsequent sections of this chapter.

WHEN SHOULD PROBLEM-SOLVING STRATEGIES BE TAUGHT?

The last question in the survey you completed at the start of the chapter concerns the issue of when to teach higher-order thinking skills—after lower-level skills have been mastered (prior automatization theory) or while lower-level skills are being mastered (constraint removal theory). According to the prior automatization view, lower-level skills should be memorized so well that they do not require any mental effort. For example, students should be able to sight-read words without hesitation before they learn reading comprehension skills. In this way, they can devote all their cognitive resources to learning the higher-order skills and not be distracted by having to think about how to use lower-level skills.

What's wrong with the prior automatization view? It means that much of school—and certainly much of elementary school—must be devoted to senseless memorizing. Students are likely to get the idea that school is not a very interesting place. In contrast, the constraint removal view holds that students can engage in higher-order skills even before they have fully mastered lower-level skills. However, the teacher must scaffold the task by removing the need to perform some of the lower-level skills. For example, if the goal is to teach reading comprehension—which is a higher-order thinking skill—but students cannot sight-read words very well, the teacher can read the passage to the students.

FIGURE 12–5
Students' lists of differences between model student and self

Jean's List

1. I didn't think it necessary to formulate the general rule. Generalization too broad. Verbalization reversed actually.
2. Lack of understanding of given terms. Define and illustrate as alternatives. I looked for "true" and "false"—others looked for "best." Didn't interpret directions properly. I looked for answer—didn't have an answer before I looked. Higher degree of inaccuracy. (I get this OK with syllogisms.)
3. He associated and brought in intermediary events with dates. I did the same with the second part, but didn't know country.
4. He employed an illustration for proof. Should set up criteria for an answer: if not enough, set up illustrations and examples.
5. Didn't get essential terms of what I was looking for before I began reading alternatives. Jumped to conclusion without carrying illustrative reasoning through. Did read terms thoroughly but didn't keep them in mind; reversed them.
6. Didn't define terms of statements. Got it right through outside example.
7. Should pull out main words. Got it right, though.
8. Didn't establish relations between terms. Got it right, though. Careless about selecting right alternative. Keeping directions in mind. I think in terms of "true" and "false" instead of "scientific study," etc.

Ralph's List

1. Find rule or formula that applies to problem under consideration.
2. Apply rule and formulate answer, then check with offered answers.
3. Progress into problem by formula that has been generalized through application.
4. Rules should deal with specific problem.
5. Try to read directions clearly the first time.
6. Do not answer by guessing or supposition.
7. Think before the formulation of answer.
8. Direct thought in stream which has been pointed in the direction of the problem at hand.
9. Emphasis on the major ideas in the problem, not all ideas.
10. Box off ideas into main question in the problem.
11. Reason from known knowledge or examples.
12. In graphs, formulate a specific picture.

Source: From Bloom B. S., & Broder, L. J. (1950). Problem-solving processes of college students: An exploratory investigation. *Chicago: University of Chicago Press. Copyright © 1950.*

Apprenticeship Chapter 13 examines the role of cognitive apprenticeship, in which beginners are allowed to work with experienced practitioners on authentic tasks. Tharp and Gallimore (1988) referred to this arrangement as *assisted performance* because students are allowed to perform challenging tasks but receive help on portions that they cannot yet perform. Similarly, Lave and Wenger (1991) showed how apprenticeship works in a wide variety of cultures—ranging from midwives in Mexico to tailors in Liberia to meat cutters in the United States. In each case, beginners work on high-level tasks but are given help on portions of the task that they have not yet mastered. These appear to be successful case studies of how people can learn higher-order skills before they have completely mastered all lower-level skills.

Criterion 4: Teach Higher-Order Skills Early Rather than Late In summary, there is increasing evidence to support the call for teaching of higher-order thinking skills to students who may not have yet mastered all relevant basic skills.

IMPLICATIONS FOR TEACHING PROBLEM SOLVING

This brief historical overview helps provide some tentative answers to our four questions. First, once you choose the kinds of problems that the students need to be able to solve, the intellectual performance required for these problems should be broken into smaller skills that can be taught instead of teaching problem solving as a monolithic ability. Second, it seems to make the most sense to teach specific problem-solving skills within specific contexts; it may also be possible to teach what appear to be general domain-free strategies, but not much evidence exists that these will transfer beyond the contexts they are taught in. Third, students should learn problem solving by focusing on process rather than product and should have models to which they can refer—that is, examples of how successful problem solvers go about solving problems. Fourth, students can learn higher-order skills even though they may not have fully mastered lower-level skills.

The next sections explore three widely used problem-solving courses that have been well received in school settings. Each is an independent problem-solving course rather than an attempt to integrate problem solving within subject matter domains. For each program, the section presents the underlying theory, briefly describes the program, and evaluates the changes in students' thinking. The three programs are the Productive Thinking Program, Instrumental Enrichment, and Project Intelligence.

Productive Thinking Program

BACKGROUND

During the 1960s, several large-scale curriculum development efforts were carried out, including projects that emphasized teaching students in elementary and secondary schools how to think. One of the best known and most thoroughly studied curriculum development projects for teaching thinking skills is the *Productive Thinking Program* (Covington, Crutchfield, & Davies, 1966; Covington, Crutchfield, Davies, & Olton, 1974), which seeks to teach general problem-solving skills to fifth- and sixth-grade students. The Productive Thinking Program involves a series of printed workbooks that provide practice in solving detective stories. Students are introduced to the process of problem solving and are invited to emulate the problem-solving strategies of models.

DESCRIPTION

The program consists of 15 cartoonlike booklets, each about 30 pages in length. Each booklet presents a detective story involving two children, Jim and Lila, as well as Jim's Uncle John and Mr. Search. The story presents clues and asks the reader to answer questions aimed at "restating the problem in his own words," "formulating his own questions," and "generating ideas to explain the mystery" (Covington & Crutchfield, 1965, p. 3). After the reader has generated some ideas, Jim and Lila give theirs. Thus, Jim and Lila serve as "models to be emulated" (p. 3). Like all realistic models, they make some mistakes at first, but with the help of comments from the adults in the booklet, they eventually figure out the mystery.

Figure 12–6 gives a few pages from one of the first lessons in the program "The Riverboat Robbery." As you read the lesson, you are given some information and asked to generate some responses. Then you get feedback by seeing what Jim and Lila do and how Uncle John critiques their strategies. (If you read the entire booklet carefully, you will discover that the culprit is Mr. Larkin, the bank manager.) Each lesson is designed to teach some of the following strategies:

1. Take time to reflect on a problem before you begin to work. Decide exactly what the problem is that you are trying to solve.
2. Get all the facts of the problem clearly in mind.
3. Work on the problem in a planful way.
4. Keep an open mind. Don't jump to conclusions about the answer to a problem.
5. Think of many new ideas for solving a problem. Don't stop with just a few.
6. Try to think of unusual ideas.
7. As a way of getting ideas, pick out all the important objects and persons in the problem and think carefully about each one.
8. Think of several general possibilities for a solution and then figure out many particular ideas for each possibility.
9. As you search for ideas, let your mind freely explore things around you. Almost anything can suggest ideas for a solution.
10. Always check each idea with the facts to decide how likely the idea is.
11. If you get stuck on a problem, keep trying. Don't be discouraged.
12. When you run out of ideas, try looking at the problem in a new and different way.
13. Go back and review all the facts of the problem to make sure you have not missed something important.
14. Start with an unlikely idea. Just suppose that it is possible and figure out how it could be.
15. Be on the lookout for odd or puzzling facts in a problem. Explaining them can lead you to new ideas for solution.
16. When there are several puzzling things in a problem, try to explain them with a single idea that will connect them all together.

"The Riverboat Robbery" attempts to teach strategies 4, 5, 6, 9, 11, and 15.

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"The Riverboat Robbery" attempts to teach strategies 4, 5, 6, 9, 11, and 15.

E 12–6
ts from "The
oat Robbery"

The TV Announcer:

"Following the robbery, things moved quickly. The captain of the boat called the Elmtown police. When the boat docked in Elmtown, the police were already on guard there. No one was allowed on or off the boat except the police and our reporter and TV cameraman."

"Here is the police chief on the boat, telling our reporter what has happened so far."

(*continued*)

EVALUATION

More than a dozen studies have evaluated the effectiveness of the Productive Thinking Program (Mansfield, Busse, & Krepelka, 1978), so "the effects of Productive Thinking have been particularly well researched" (Adams, 1989, p. 38). For example, Olton and Crutchfield (1969) gave training in the Productive Thinking Program to 25 fifth graders,

FIGURE 12–6

(continued)

1

What persons besides Louie might be the thief?

Before Lila tells her idea, what thoughts do you have about other possible suspects? Use your reply notebook to write down all the ideas you can think of.

There are several people besides Louie who might have stolen the money. You may have thought of the steward who called Mr. Burk to the phone, or perhaps you even considered the riverboat captain.

Lila has another possible suspect in mind.

(*continued*)

while an equal number of fifth graders received no training. Here are some examples of pretests given before training, posttests given immediately after training, and delayed posttests given 6 months after training.

Uncle John is right. You can always think of more ideas. And you should never be afraid to talk about your ideas.

Source: From The Productive Thinking Program by Convington, M. V., Crutchfield, R. S., Davies, L. B., & Olton, R. M. (1979). The Productive Thinking Program, Columbus, OH: Merrill.

Pretests

Controlling the weather: Student thinks of various consequences of humans' future ability to change the weather.

Project for a village: Student puts himself in the shoes of a Peace Corps volunteer who must first acquaint himself with the customs and mores of a tribal village. Then, without offending such customs, he must figure out ways the inhabitants can earn money for their village needs.

Immediate Posttests

Transplanting organs: Student thinks of various consequences of humans' future medical ability to transplant bodily organs from one person to another.

"Black House" problem: Student attempts to solve a puzzling mystery problem in which he must make an insightful reorganization of the elements of the problem.

Delayed Posttests

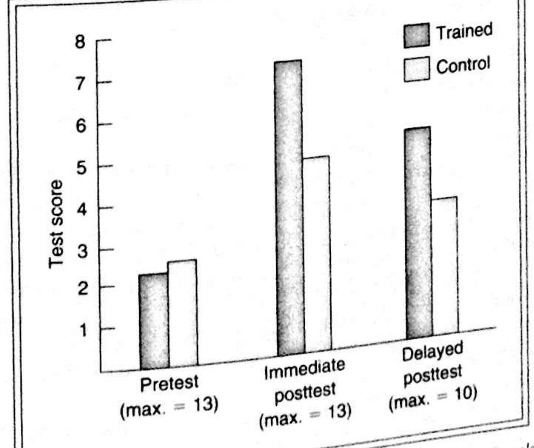
The missing jewel problem: Student attempts to solve a puzzling mystery problem in which she must make an insightful reorganization of the elements of the problem.

The nameless tomb: Student works on a hypothetical problem in archeology in which she must discover which of 10 possible suspects is buried in a nameless ancient tomb.

Figure 12–7 shows that the trained group and control group scored at about the same level on the pretest, but the trained group outperformed the control group on the immediate and delayed posttest.

In interpreting these results you should note that the test problems were similar to the types of problems given in the booklets and that factors other than training, such as higher motivation by the trained subjects, may account for differences among the groups. In a review of a dozen evaluation studies, Mansfield et al. (1978) concluded that the effects of the Productive Thinking Program are smaller in well-controlled studies and seem limited to problems like those given in the lessons. Concerning the issue of transfer of problem-solving strategies to new problems, Mansfield et al. (1978) concluded that "it is unclear whether the effects of training are sufficiently generalizable to be useful in real-life problem solving situations" (p. 522). Nickerson (1999) also noted "the limitation of the gains to problems similar to those encountered in the program material" (p. 402). Apparently, it is possible to teach students to perform well on a certain class of problem, but no strong evidence exists that such training transfers to other domains.

FIGURE 12–7
Effects of training in productive thinking on creativity



Source: Adapted from Olton, R. M., & Crutchfield, R. S. (1969). Developing the skills of productive thinking. In P. Mussen, J. Langer, & M. V. Convington (Eds.), New directions in developmental psychology. New York: Holt, Rinehart and Winston.

Overall, the Productive Thinking Program is consistent with the criteria for a successful thinking skills program: It teaches a limited number of component skills (as listed on page 443), its effects are strongest for the specific domain used during instruction, the instructional method relies heavily on modeling of cognitive processing, and it seeks to attain higher-order skills even though learners may not have yet mastered all lower level skills.

Instrumental Enrichment

BACKGROUND

Suppose a boy develops in an environment that does not offer much human contact or much opportunity to learn. After many years of living this way, the boy is brought to school, where he performs poorly on intellectual tasks and is labeled "mentally retarded." You might be somewhat skeptical of this labeling and ask questions such as "Does the boy have potential for a higher level of intellectual functioning than he is currently performing?" "What types of natural experiences would lead to the boy's reaching or not reaching his highest potential?" "If the boy missed many of the natural experiences needed for intellectual development, can instruction help him reach a higher level of intellectual functioning?"

These kinds of questions were addressed by Feuerstein (1979, 1980; Feuerstein, Jensen, Hoffman, & Rand, 1985; Kozulin & Rand, 2000), based on his work with special education adolescents in Israeli schools. First, if a student performs poorly on academic tasks, Feuerstein prefers to label that child a "retarded performer." Feuerstein found that it is useful to make a distinction between a child's manifested low level of functioning (i.e., retarded performance) and the child's actual potential for intellectual performance. He even developed a test called the learning potential assessment device (LPAD) to evaluate how much improvement he could expect for each retarded performer. Instead of being a static mental ability test, the LPAD presents the student with learning tasks and measures the amount of teacher intervention needed to help the student accomplish the tasks.

Second, Feuerstein noticed that students who have trouble learning in school often come from homes in which parents do not explain, discuss, or interpret events (including their culture) to their children. Feuerstein notes that such children are *mediationally deprived*; that is, the normal events in their lives do not seem to have any meaning or purpose because no one provides any interpretation of them. Mediationally deprived students have trouble responding to new problems or new learning tasks. According to Feuerstein, these children have been denied exposure to what he calls *mediated learning experiences* (MLEs). For example, in playing with a typewriter, a child can learn about cause and effect. A parent might say, "When you press the A key, it makes this metal strike the ink and print a letter A on the paper." As another example, a family trip to the beach can be the basis for learning to plan. A parent might say, "Bring your bucket and shovel in case you want to build sand castles." As another example (Feuerstein, 1980, p. 21), a parent can ask a child to go to the store: "Please buy three bottles of milk so that we will have some left over for

tomorrow when the shops are closed." This example demonstrates the role of planning much more than the statement "Please buy three bottles of milk." In these examples of MLEs the parent helps interpret events so that the child can see the meaning or purpose or intentionality in the surrounding world.

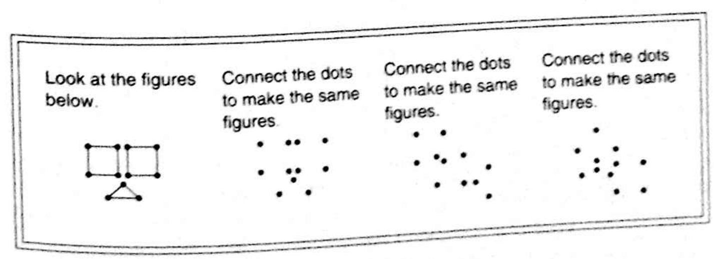
Third, Feuerstein developed a program called *Instrumental Enrichment (IE)* that is intended to provide low-functioning students with the kinds of mediated learning experiences that children normally receive. To compensate for the inadequate MLEs of his students, he provides them with a series of problems—each one different—that serve as the basis for discussion and interpretation with an adult. Feuerstein's Instrumental Enrichment program is recognized as "possibly the most widely used program for intellectual-skills training in the world" (Sternberg, 1991, p. x).

DESCRIPTION

Feuerstein's instructional enrichment (IE) program consists of a series of paper-and-pencil exercises for low-functioning adolescents. The program is intended to be administered as an adjunct to regular academic instruction; for example, IE could occur for 3 to 5 hours per week over a 2-year period, for a total of 200 to 300 hours. The tasks are organized into 15 instruments, with each instrument focusing on one or more cognitive skills.

Figure 12–8 gives an example exercise from the "Organization of Dots," the first instrument in the IE program. The student's job is to connect the dots so that they form the same shapes as in the model (i.e., two squares and a triangle). Each dot can be used only once, and each shape must be the same size as in the model. However, the drawn shapes can overlap and be in different orientations than the model shapes are. For each exercise, the teacher introduces the problem and allows for individual work on the problem. Then the class discusses methods for solving each problem and the teacher summarizes them. Thus, students get exposed to many novel problems and learn to compare their approach to the methods used by others. Because each problem is novel, the students cannot memorize answers. Exercises such as these are intended to teach students how to generate and evaluate problem representations and solution strategies. The problems are organized so that they increase in difficulty. According to Feuerstein, the Organization of Dots problems teach students the following cognitive skills: breaking a problem into parts, representing a problem, and thinking hypothetically. Other instruments focus on spatial orientation,

FIGURE 12–8 Example exercises from the Organization of dots



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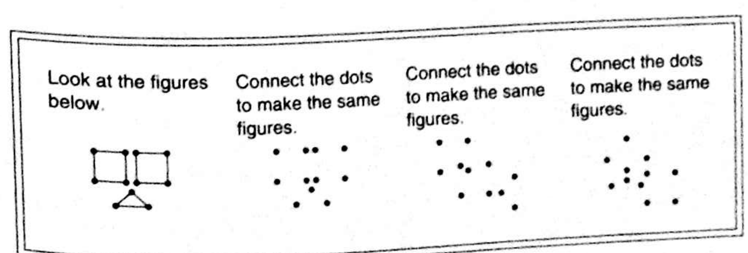


Adapted from Feuerstein (1980).

temporal relations, family relations, numerical progressions, analytic perception, transitive relations, and syllogisms.

EVALUATION

Does the IE program help students become better able to deal with new problems (i.e., to become better thinkers)? Feuerstein and colleagues (1980; Feuerstein, 1979) report an evaluation study comparing adolescent special education students who received IE over a 2-year period with students who received the normal enrichment procedures. Both groups performed at the same level on pretests of cognitive skill, but after 2 years, the IE group scored higher on tests involving spatial and mathematical reasoning (i.e., tests of spatial relations, figure grouping, number, and addition). Follow-up studies on the same students 2 years later found the IE group still scored higher than the control group on tests of nonverbal intelligence. In a more recent study involving adolescents with mental retardation, two years of IE treatment resulted in greater improvements on cognitive ability tests than did a general enrichment treatment (Feuerstein, Rand, Hoffman, & Miller, 2004). Importantly, the IE group also showed a greater improvement in academic achievement than did a group receiving general enrichment.

Blagg (1991) conducted "arguably the most thorough and carefully planned evaluation of an intellectual-skills training program that has been done" (Sternberg, 1991, p. x). Low-achieving 14-year-old students from four schools in England received 2.0 to 2.5 hours of IE training per week, for an average of 112 hours over the course of the training. Overall, the IE training did not produce significant increases in general intelligence, reading skills, or mathematics skills, but teachers indicated that students became more active contributors to class discussions, more likely to defend their opinions on the basis of logical evidence, more able to describe different strategies for solving problems, and more likely to spontaneously read and follow instructions carefully. Even these positive changes, however, did not generalize to other subject areas; that is, they were not observed by other teachers. In a review of Blagg's study, Haywood (1992) pointed to flaws in the way that teachers were trained and supervised. Similarly, Kozulin and Presseisen (1995) provided evidence that "the amount of IE instruction, the quality of the mediation provided by the IE teacher, and the presence of special bridging exercises to content areas of curriculum constitute the decisive factors of success in IE implementation" (p. 73). In a more recent review of 40 controlled studies, Romney and Samuels (2001) found evidence that exposure to IE produced modest gains in intellectual ability, although the effects depend on length of exposure.

Feuerstein's program seems consistent with the four criteria for a successful program described in the preceding section. First, the program content focuses on a set of small cognitive tasks, mainly specific strategies for representing problems and planning solutions. Second, although the program appears to teach general problem-solving skills independent of subject matter area, the skills that are taught actually are quite specific and similar to tasks on nonverbal intelligence tests. Bransford, Arbitman-Smith, Stein, and Vye (1985) point out that "there is an emphasis on training students to solve certain types of problems so that they will be able to solve similar problems on their own within each instrument" (p. 201). However, Feuerstein does not assume that learning one instrument—that is, one kind of problem—will help a student learn another instrument that requires different cognitive skills. Instead, the IE program seems to be providing students with many specific subskills

that, taken together, are useful for performance on tests of nonverbal intelligence. Third, the method involves lots of practice in modeling of the processes used by successful problem solvers. Fourth, the program does not wait until the learner has mastered all basic skills before attempting to teach higher-order skills.

Project Intelligence

BACKGROUND

Consider the following scenario: The country you live in has decided to make a national commitment to improving the intellectual performance of its citizens. The nation's president has appointed you as the first Minister of State for the Development of Human Intelligence. What can you do to improve the people's problem-solving skills?

Although this may seem like an artificial problem, it was a real problem for Dr. Luis Alberta Machado, who was appointed in the 1980s to head the new Ministry for the Development of Human Intelligence in the country of Venezuela, the first such ministry in the world. Minister Machado (1981) summarized the rationale for his ministry as follows:

> In the same way that investment of resources and political strategy are planned so should the different nations by means of a common effort, plan the attainment of a higher degree of intelligence in the least time possible by all mankind. . . . When the necessary means are organized to systematically improve the intelligence of all people, mankind will have taken the most important step towards progress (pp. 3–4).

Similarly, Dominguez (1985) noted that "in Venezuela we are attempting to put these ideas about the modifiability of human intelligence to work in the service of mankind" (p. 531).

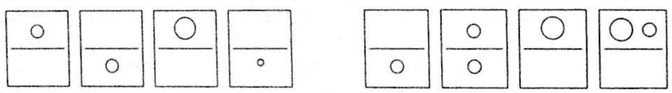
As part of his assignment, Dr. Machado enlisted a group from Harvard University, Bolt Beranek and Newman (a research and development company in Cambridge, Massachusetts), and the Venezuelan Ministry of Education to develop a 1-year course in thinking skills for seventh-grade students in Venezuela. A primary goal of the course was "to raise the intelligence of participating Venezuelan seventh graders" (Martinez, 2000, p. 157), and the project was named "Project Intelligence." Importantly, the thinking skills course—named Odyssey—was to receive a rigorous, scientifically valid evaluation, a feature that is sometimes lacking in curriculum development efforts.

DESCRIPTION

Odyssey consists of one hundred 45-minute lessons, presented across six lesson series (or books)—Foundations of Reasoning, Understanding Language, Verbal Learning, Problem Solving, Decision Making, and Inventive Thinking (Adams, 1986, 1989). Within each lesson series, the lessons are arranged into units that share a similar theme—such as six lessons on classifying items based on their characteristics ("observation and classification"), five lessons on recognizing patterns in orderings ("ordering"), and four lessons on solving analogy problems ("analogies").

To ensure consistent classroom implementation, each lesson followed the same format based on suggested scripts, although "the scripts were not intended to be followed literally in class" (Nickerson, 1994, p. 857). For example, Figure 12–9 shows a problem and proposed teaching script for a lesson on sequences and change contained in the first book, Foundations of Reasoning. The lesson begins by the teacher leading a discussion on how to solve some sample problems. Then students are given an opportunity to solve some problems on their own. Finally, students are asked to explain their solutions to others. This

URE 12–9 An ssey lesson



TEACHER: Observe the first figure of row one. What does the first box in row one contain?
STUDENT: A line with a circle above it.

TEACHER: Look at the second box. What does it contain?
STUDENT: The same line with a circle beneath it.

TEACHER: What change has taken place?
STUDENT: The position of the circle has changed from above the line to below the line.

TEACHER: Observe the third figure. How has it changed from the second?
STUDENT: The circle returned to the upper part, and it has become larger.

TEACHER: Look at the fourth figure. What has happened now?
STUDENT: The circle is again below the line, and it has become smaller.

TEACHER: Along how many dimensions have we observed changes? What are they?
STUDENT: Two. The circle has changed positions with respect to the line, from above to below, from below to above, and from above to below. The circle changed size in the third and fourth figures.

TEACHER: Yes. One of these changes occurred in all four of the figures, and one in only two. Which is the change that all of these figures share?
STUDENT: The change in the position of the circle.

TEACHER: Yes. And would you call the changes in the position of the circle alternating or progressive?
STUDENT: Alternating.

TEACHER: Yes. The circle moves from above to below to above, repeatedly, so it is an alternating sequence.

Source: Adapted from Adams, M. J. (1986). Odyssey: A curriculum for thinking. Watertown, MA: Charlesbridge Publishing. Copyright © Charlesbridge Publishing, 85 Main Street, Watertown, MA 02472. Used with permission.

lesson is intended to teach some fairly specific target skills, such as identifying which dimensions to pay attention to, distinguishing among various types of changes, and recognizing the next item in a sequence on the basis of previous changes in a given dimension. Adams (1989) noted that "the thrust of the course was to be conveyed through direct instruction modeled on the Socratic Inquiry Method . . . and capitalizing on structured discovery" (p. 70).

EVALUATION

Does a year's worth of Odyssey help students become better thinkers? In a well-controlled evaluation study (Herrnstein, Nickerson, Sanchez, & Swets, 1986; Nickerson, 1994), 463 seventh-grade students from six schools in Venezuela received 45-minute training sessions for 4 days per week over the course of an academic year (covering 56 lessons), whereas a matched control group did not receive any special training in thinking skills. Students in both groups were tested on a battery of cognitive tests before and after the course. Although both groups improved, the trained group improved more than twice as much as the control group on cognitive skills that were specifically targeted in the program, indicating the course was successful in teaching targeted thinking skills. Interestingly, the trained group also improved more than the control group on several intelligence tests, although the differences were much smaller (with the trained group showing improvements ranging from 21% to 68% more than the control group). Nickerson points out, "It was not feasible to obtain data in subsequent years" (p. 859), so it is not possible to know whether the effects of the program were longlasting. Overall, "Project Intelligence enhanced the magnitude of students' intelligent behavior and transferability to new and authentic tasks, at least in the short term" (Grotzer & Perkins, 2000, p. 496).

Project Intelligence, and its courseware Odyssey, is offered as an exemplary success story in the teaching of thinking (Adams, 1989; Grotzer & Perkins, 2000; Martinez, 2000; Nickerson, 1994; Perkins & Grotzer, 1997). In short, it has earned its place among "an increasing number of studies [that] provide evidence that targeted attempts to teach people to think better can be worthwhile" (Perkins & Grotzer, 1997, p. 1126). As you can see, the course is consistent with the criteria for successful thinking skills programs: It targets a collection of component skills, the skills are taught within the specific context that students are expected to use them, teachers and students model and discuss the process of problem solving, and the higher-order skills are taught before all lower-level skills are mastered.

The Case for Improving Problem-Solving Skills Instruction

In the previous sections, you learned about three classic problem-solving courses that have been used in schools. Of course, many other problem-solving courses (Chance, 1986; Chipman, Segal, & Glaser 1985; Grotzer & Perkins, 2000; Martinez, 2000; Nickerson, Perkins, & Smith, 1985; Perkins & Grotzer, 1997; Ritchhart & Perkins, 2005; Segal, Chipman, & Glaser, 1985) have been developed but these three courses are among the most carefully evaluated. How do the programs we have reviewed rate on the four criteria for an effective problem-solving program? Consistent with the criteria, each program focuses on a set of specific problem-solving skills, contextualizes the skills within tasks like those the learner is expected to perform, gives students practice in the process of problem solving (including modeling of good procedures), and teaches higher-order skills before students have mastered lower level skills. Consistent with this emphasis on teaching domain-specific skills and strategies, a recent review of effective creativity training programs also concluded that the "more successful programs were likely to focus on development of cognitive skills and hueristics . . . using realistic exercises appropriate to the domain at hand" (Scott, Leritz, & Mumford, 2004, p. 361).

What is the place of general thinking skills courses? Given the importance of the issue, you might be surprised that there has not been more research on the cognitive consequences of thinking skills courses. Perhaps it is easier to develop and market thinking skills courses than to determine whether they promote appropriate cognitive changes in learners. There is some reason for optimism, however, because each of the three courses we examined appear to be supported, at least under some circumstances, by solid evaluation results. Yet, in some respects, we are faced with a paradox. Although these problem-solving courses appear to deal with general thinking ability, they actually focus on a series of individual skills that help performance mainly on specific tasks like those used in the program. It follows that a more fruitful approach to the teaching of problem solving would be to identify target tasks required for success in school and then teach the cognitive processing skills required to succeed on those tasks. Embedding problem-solving instruction within specific courses makes good sense, given the domain-specificity of problem solving (Mayer, 1999), and is the approach taken in a new generation of successful programs. Thus, I presented these three classic programs only as examples to be examined rather than as a sort of endorsement.

This review suggests that the future of problem-solving instruction rests with subject-matter-specific programs targeted to specific cognitive skills, such as teaching students how to comprehend text through reciprocal teaching (Brown & Palinesar, 1989; Palinesar & Brown, 1984) as described in Chapter 13, teaching students how to mentally represent arithmetic word problems (Low & Over, 1989, 1990, 1993) as described in Chapter 5, or teaching students how to analyze scientific information in a web-based information-gathering environment (Azevedo & Cromley, 2004) as described in Chapter 11. In addition future instructional efforts need to be sensitive to learners' individual differences such as their amount of prior knowledge. For example, Zohar and Dori (2003) reported that teaching of thinking skills to high school science students was more effective for higher achieving students than for lower achieving students, suggesting that different techniques might be appropriate for students with low and high amounts of prior knowledge. Finally, technology can play a role in teaching thinking skills. For example, Kumta, Tsang, Hung, and Cheng (2003) developed an interactive web-based tutorial program to teach thinking skills to medical students, which resulted in improvements in medical problem-solving tasks as compared to a control group.

The new generation of thinking skills instruction is based on four guiding principles:

1. *Focus on a few well-defined skills.* Nebulous skills such as "improving intelligence" or "teaching thinking" must be recast as well-defined target skills such as "being able to identify an unclear sentence." For example, in the reciprocal teaching program,

students learn four well-defined comprehension strategies: *questioning*, in which a student creates an appropriate question answered by the passage; *clarifying*, in which a student identifies a potentially confusing part of the passage; *summarizing*, in which a student produces a summary for a passage; and *predicting*, in which a student suggests what will occur next in the passage. Rather than try to improve students' "verbal comprehension skills" as a monolithic ability, the program seeks to teach a focused collection of effective strategies.

2. *Contextualize the skills within authentic tasks.* General skills such as "planning" must be recast within a specific context such as "planning an outline for writing an essay." For example, in the reciprocal teaching program, students work on authentic tasks, such as trying to make sense of actual text found in a classroom book. Rather than work on contrived exercises, students work on a real academic task.
3. *Personalize* the skills through social interaction and language-based discussion of the process of problem solving. Practice on getting the right answer must be recast as including discussion of the problem-solving process. For example, in the reciprocal teaching program, students work in discussion groups, taking turns playing the role of the teacher. They hear the teacher model how she or he goes about using a strategy. They get to try to describe their own cognitive processes and receive critiques from others. Rather than work alone at their seats, students engage in a community of learners working together to learn.
4. *Accelerate the skills so that students learn them along with lower-level skills.* The order of learning must be recast so that the focus is on learning to use both low- and high-order skills. For example, in the reciprocal teaching program, students learn high-order skills such as how to summarize at the same time they learn low-order skills such as how to produce grammatically correct sentences. Rather than having to completely master sight-reading skills before learning comprehension skills, students are able to learn both kinds of skills together.

Where will the new generation of thinking skills instruction take us? Instead of relying solely on general problem-solving courses, every subject matter will incorporate teaching relevant cognitive skills. Mayer (1999) shows how school subjects such as reading, writing, mathematics, and science can be analyzed into component cognitive processes that students can learn. Rather than seek to improve scores on intelligence tests, the goal is to help students develop cognitive skills they need to excel on real academic tasks ranging from comprehending a passage to writing an essay to solving a mathematical business problem to testing a scientific theory. In addition to developing domain-specific cognitive skills, students also need to learn domain-specific metacognitive skills (as described in Chapter 11) so they can become self-regulated learners—that is, learners who take responsibility for monitoring and controlling their cognitive processing on academic tasks (Azevedo & Cromley 2004; Pintrich & Zusho, 2002; Winne, 2005).

Let's return for a moment to the thorny problem of Project Head Start—perhaps, the world's boldest experiment in improving human cognition. Overall, research shows that students who receive experience in Head Start score higher on intelligence tests than matched control students immediately after instruction, but the IQ advantage fades away after 1 or 2 years (Martinez, 2000; Zigler & Muenchow, 1992). In short, the program appears to be successful in promoting cognitive change, but the cognitive effects are not long-lived. How can this be explained? First, the content of Head Start programs is sometimes not well defined. Research on teaching thinking shows that the most successful programs begin with a small collection of well-defined skills. Second, the instructional methods used in Head Start may not be consistent with the project goals. Research on teaching thinking skills shows the advantages of helping students discuss the process of problem solving. Third, the assessment of Head Start programs is closely tied to IQ gains, but research on teaching thinking skills shows that improvements occur mainly in the specific domains that were taught. Finally, Head Start represents a fairly short-term experience involving only a small part of the child's life. Yet the teaching of appropriate cognitive skills requires a broad, long-term commitment. The most important lesson of Project Head Start is that the teaching of cognitive skills—including problem-solving strategies—requires an effective and continuing instructional program.

Chapter Summary

This chapter investigated techniques for teaching students how to think. Four important issues for designing instruction in thinking skills are (1) what to teach (i.e., is problem solving a single ability or many component skills?); (2) where to teach (i.e., should problem solving be a separate course or be integrated into specific subjects?); (3) how to teach (i.e., should students practice giving the right answers for problems or discuss the process of solving problems?); and (4) when to teach (i.e., should students master lower-order skills before learning higher-order skills?). Historically, schools began by teaching thinking as if it were a single ability; however, systematic research seems to show that problem-solving training is most effective when the material to be taught consists of a collection of well-defined component skills. Historically, schools have taught thinking skills independent of subject-matter domains in hopes that such skills would transfer to many situations; however, systematic research shows that students tend to learn specific skills that can be applied mainly in the same kinds of contexts as the examples used during instruction. Historically, schools began with attempts to teach thinking skills through drill-and-practice in applying rules; however, systematic research suggests that students also profit from generating and analyzing worked-out examples and comparing their own solution processes to those of experts. Historically, schools began by insisting that basic skills be mastered before higher-order skills were taught; however, systematic research shows that higher-order skills can be learned along with lower-level ones.

This chapter reviewed three popular problem-solving courses—the Productive Thinking Program, Instrumental Enrichment, and Project Intelligence. All share a focus on individual skills (rather than general ability), being more effective on tests of specific transfer (rather than general transfer), teaching the process of problem solving (rather than focusing on product), and teaching higher-order skills before lower-level skills are mastered (rather than after).

The new generation of thinking skills instruction builds on these principles, and is exemplified by reciprocal teaching of comprehension strategies as described in Chapter 13, problem representation strategies as described in Chapter 5, and metacognitive strategies as described in Chapter 11.

SUGGESTED READINGS

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