Kinds of Thinking Taught in Current Programs

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Among my childhood memories is that of my parents scolding me for not thinking before doing something that produced an unhappy and, to them, predictable consequence. They assumed—probably rightly—that their task was not teaching me how to think but *motivating* me to do so.

Surely, in one sense, all of us know how to think without being taught; the problem is to get us to do so with some consistency. The admonition to think before acting, to consider the possible consequences of our actions before committing to them, is one that we understand even though we may fail to heed it in practice. To the extent that this is so, one reasonable goal of education would be to make students more aware of the importance of stopping to think before acting—leaving *think* undefined on the assumption that everyone knows intuitively what it means in this context—and of motivating them to adopt a reflective attitude and a deliberative approach to daily problems and decision situations as a matter of habit. I believe this is indeed a legitimate goal, which, if energetically pursued, could have substantial positive effects.

On the other hand, our failure to think through to the solution of a problem is not always for lack of trying. Sometimes the motivation is there but not the ability. In such cases, what we need to be shown is *how* to think in more productive ways. The ques-

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Some thinking skills programs emphasize cognitive processes, while others are concerned with heuristics, development of formal operations, language and symbols, or thinking as subject matter.

tion now is this: are there things that can be taught to improve one's thinking more or less independently of the context in which, or the purpose for which, the thinking is done? Can we be taught to be more rational, more creative, more perceptive, more insightful, more generally effective in the performance of intellectually demanding tasks? The belief that thinking ability can be enhanced through teaching has led to the development of a number of formal programs with this objective.

But do we need *special* approaches to the teaching of thinking skills? Is not

John McNamara

John McNamara

the enhancement of thinking ability a major objective of primary and secondary education already? Clearly, the teaching of logic is aimed at facilitating thinking of the most rigorous kind. And what is mathematics, after all, if not a set of tools for thinking quantitatively about problems and for structuring approaches to their solutions? In learning about the sciences—physics, chemistry, biology—one acquires concepts and a knowledge of relationships, principles, and processes without which one could not think effectively about these subjects. Even in the cases of such basics as reading and writing, a major objective is to enhance thinking ability: literacy provides access to a world of ideas that otherwise would not be available, and one cannot learn to write effectively without learning how to organize one's thoughts and to express them clearly.

The enhancement of thinking ability is, indeed, at least implicitly, a major objective of the educational process as it is instituted in this country and elsewhere. Moreover, much is undoubtedly being done by individual teachers to develop and enhance the thinking abilities of their students. Unfortunately, in spite of the efforts and successes of many teachers, many students graduate from high school without acquiring the ability to deal effectively with intellectually demanding problems. A sizable fraction of high school graduates who are about to enter college are not adequately prepared to do the kind of thinking their college experience will require of them (Carpenter, 1980; Karplus, 1974; Renner and Lawson, 1973; Tomlinson-Keasey, 1972). Students frequently get through basic math and science courses with no more than a superficial understanding of the concepts and relationships that are central to the subjects they have studied and without the ability to apply those concepts and relationships effectively to real-world problems (Carpenter and others,

1980; Clement, 1982; Trowbridge and McDermott, 1980; McCloskey, Caramazza, and Green, 1980; Nickerson, 1982). The increasing interest in the teaching of thinking skills, and in particular in the desirability of teaching them explicitly, stems in large part from concerns about such documented failings of the current system. This interest is also supported, however, by the belief that the considerable research that has been done in recent years on human thinking—reasoning, problem solving, decision making, metacognition—has yielded enough new knowledge about thinking to give such an enterprise something of a scientific base.

Examples of Programs to Teach Thinking

Programs that have been developed to teach thinking skills in the classroom differ from one another on many dimensions, including the following (Nickerson, Perkins, and Smith, in press):

- Scope.
- Specific skills addressed.
- Ages and academic abilities of participating students.
- Amount and distribution of class time devoted to the program.
- Amount of special training given to teachers.
- Amount and type of program material (instructions to teachers, student exercises, or workbooks).
- Latitude given to teachers.
- Completeness and availability of documentation.
- Degree of integration with other courses.
- Amount of emphasis on evaluation.
- Evaluation instruments used.
- Evidence of effectiveness.

The wide variety of approaches currently being tried is testimony to the fact that people hold different opinions regarding how best to proceed. My colleagues, David Perkins and Edward Smith, and I have found it convenient to group programs to teach thinking in five categories: (1) cognitive-process approaches, (2) heuristics-oriented approaches, (3) approaches that focus on the development of formal thinking in the Piagetian sense, (4) approaches that emphasize language and symbol manipulation, and (5) approaches that focus on thinking as subject matter. This scheme is far from perfect; there are programs that could fit almost equally well in more than one of these categories. The various programs differ from each other in so many ways, however, that any classification scheme is likely to have some arbitrariness about it. We view this one as primarily a matter of convenience, but it does help make some useful distinctions. More extensive descriptions of the programs mentioned here and of others are given in Nickerson, Perkins, and Smith.

Cognitive Processes

Cognitive-process approaches assume that thinking ability depends on certain fundamental processes such as comparing, ordering, classifying, inferring, and predicting. Such processes are considered to have wide applicability and are assumed to be essential to the performance of many intellectually demanding tasks. They typically are treated as basic and not divisible into still simpler constituents.

Instructional strategy in the programs that emphasize basic cognitive processes typically involves exercising these processes in a variety of contexts. A student is given practice in making comparisons of different types, in ordering, in classifying objects according to an assortment of criteria, and so on. The assumption is that extensive practice with such tasks will strengthen the underlying processes and make them more readily accessible for application to other contexts in which they can be useful.

The basic cognitive processes are considered more or less as "muscles of the mind" that can be strengthened through use. Mental ability is assumed to be enhanced in a global way to the extent that it has a full complement of such processes upon which to draw. Programs to teach thinking skills that might be considered examples of cognitive-process approaches include Feuerstein's *Instrumental Enrichment* program (Feuerstein, Rand, Hoffman, and Miller, 1980); the *SOI* program

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developed by Meeker (1969); and the *Science—A Process Approach* (SAPA) program (Gagne, 1967). Also, part of the *Project Intelligence* material (see Figure 1) fits in this category.

Cognitive-process programs have considerable face validity, inasmuch as there is no denying the importance of the processes on which they focus. With or without special training, we all use these processes in our daily lives: we compare, order, classify, and infer more or less constantly. That is not to say, of course, that we do these things as well as they can possibly be done. One question of interest, and still an open one in my view, is whether giving people practice in using these processes in structured situations makes the processes more efficient or more available for general use. Another is whether it is possible to give people explicit instruction regarding how to use any one of these processes more effectively.

Programs for Teaching Thinking

SOI (Structure of the Intellect)

Developer:	Mary Meeker (based on Guilford)
Goal:	Equip students with the necessary intellectual skills to learn subject matter and critical thinking.
Sample skill:	NMI—CoNvergent Production of SeMantic Implications (choosing the best word)
Assumptions:	Intelligence consists of 120 thinking abilities, which are a combination of: *operations* (such as comprehending, remembering, and analyzing), *contents* (such as words, forms, and symbols), and *products* (such as single units, groups, relationships). • Twenty-six of these factors are especially relevant to success in school. • Individual differences in these factors can be assessed with the SOI-LA tests and improved with specifically designed SOI materials.
Intended audience:	All students and adults.
Process:	Students use materials (some three dimensional) prescribed for them based on a diagnostic test. Computer software gives analyses and prescriptions.
Time:	Varies, but can be 30-minute lessons twice a week until abilities are developed on post-assessment.
Available from:	SOI Institute 343 Richmond St. El Segundo, CA 90245

Heuristics

Heuristic, as the word is used in the literature on problem solving, is roughly synonymous with *strategy*. A heuristic is an approach to a goal that is believed to have a good chance, but not certainty, of success. Typically, heuristics are used on problems that are sufficiently complex that an algorithmic approach—a detailed step-by-step prescription that is certain to succeed—is not possible.

The mathematician George Polya (1957) was one of the first people to promote the idea that there are certain heuristics worth learning because they are applicable to problem solving more or less independently of the nature of the problem. Heuristics he identified include:

- Represent the problem with a graph or diagram.
- Restate or reformulate the problem.
- Break the problem into parts.
- Think of a known problem that is similar to, but simpler than, the one you are trying to solve.

Heuristics-oriented approaches show the strong influence of research on cognitive psychology (especially problem solving) and artificial intelligence. Researchers in both these areas have been interested in understanding better how people, especially experts, go about solving problems of different types. Researchers in artificial intelligence have been seeking the kind of information that would make it possible to codify problem-solving processes so they can be represented in computer programs.

Educational researchers are interested in two questions relating to expertise: (1) does the performance of experts as a group differ from that of novices, and (2) does the performance of experts in different domains have certain characteristics in common? If experts as a group tend to approach problems differently from novices, perhaps one way of helping novices become experts would be to teach them explicitly how experts approach problems.

Figure 1. Outline of Skills—Project Intelligence

Marilyn J. Adams
Jose Buscaglia
Allan M. Collins
Carl E. Feehrer
Mario C. Grignetti
Richard J. Herrnstein
Susan Herrnstein
A. W. F. Huggins
Catalina Laserna
Raymond S. Nickerson
David N. Perkins
Margarita de Sanchez
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Brenda J. Starr
John A. Swets

An effort to design, implement, and evaluate a course in thinking at the 7th grade level in Venezuela, Project Intelligence was a collaboration of Harvard University, Bolt Beranek and Newman Inc., and the Venezuelan Ministry of Education. The project was initiated by the Minister of State for the Development of Intelligence and funded by Petroleos de Venezuela.

The major product of the effort is a Teacher's Manual of 99 lessons, each of which provides material and guidance for one 45-minute classroom session. The lessons, which have not yet been published in English, are organized into 20 units of three or more lessons each; the units are in turn organized into six series, which represent major themes related to thinking.

I. FOUNDATIONS OF REASONING

A. *Observation and Classification*
- Observation
- Differences
- Similarities
- Groups and Essential Characteristics
- Classes and Classification
- Hypothesis Testing

B. *Ordering*
- Sequences and Change
- Orderable Dimensions
- Orderable Dimensions and Relative Descriptions

C. *Hierarchical Classifications*
- Definitions of Hierarchical Classification
- Applications of Classification Hierarchies
- Interpreting and Using Hierarchies

D. *Analogies: Discovering Relationships*
- Solving Analogies
- The Bidirectional Relationship of Analogies
- Group Analogies
- Completing Analogies

E. *Spatial Reasoning and Strategies*
- The Tangram
- True Tangrams
- Visual Projection

II. UNDERSTANDING LANGUAGE

A. *Word Relations*
- Antonyms
- Synonyms
- Word Classification
- Analogies and Metaphors

B. *The Structure of Language*
- The Relation Between Order and Meaning
- The Structure and Purpose of Paragraphs
- Main Ideas and Topic Sentences
- Rhetorical Structure

C. *Reading for Meaning*
- Understanding the Author's Message
- Interpreting Beliefs, Feelings, and Goals
- Understanding Different Points of View
- Adopting Different Points of View
- The Importance of Previous Experience

III. VERBAL REASONING

A. *Assertions*
- Form Versus Meaning
- Common Forms of Assertions with Quantifiers
- Establishing Truth and Falsity of Universal and Particular Assertions
- Using Diagrams to Represent Assertions
- The Nonreversibility of Positive Universal Assertions
- The Reversibility of Negative Universal Assertions
- Restating Assertions
- Relationships Between Assertions
- Counterexamples and Contradictions

B. *Arguments*
- Understanding Arguments
- Validity Versus Truth
- Using Diagrams to Help Judge the Validity of Arguments
- Some New Forms of Logical Arguments
- Dealing with Incomplete Arguments
- Evaluating Plausible Arguments
- Opposing Arguments and Counterarguments
- Constructing and Evaluating One's Own Arguments

IV. PROBLEM SOLVING

A. *Linear Representations*
- Direct Statements
- Statements with Order Reversal
- Statements in Difficult Language
- Indeterminate Statements
- Inventing Statements

B. *Tabular Representations*
- Numerical Tables
- Numerical Tables with Zeroes
- Truth Tables

C. *Representation by Simulation and Enactment*
- Simulations
- Flow Diagrams
- Consolidation Exercises
- Transfer Exercises

D. *Systematic Trial and Error*
- Trial Answers
- Exhaustive Searches

E. *Thinking Out the Implications*
- Thinking About the Givens
- Thinking About the Solution

V. DECISION MAKING

A. *Principles of Decision Making*
- What Are Decisions, Who Makes Them, and When?
- Why Are Some Decisions Difficult to Make?
- Choosing Alternatives with Known and Unknown Outcomes

B. *Gathering and Evaluating Information to Reduce Uncertainty*
- Outcome Possibility Assessment
- Relevance of Information
- Consistency of Information
- Credibility of Information

C. *Analyzing Complex Decision Situations*
- Establishing Preference
- Weighting Dimensions

VI. INVENTIVE THINKING

A. *Design*
- Analyzing a Design
- Comparing a Design
- Imagining Changes
- Evaluating a Design
- Improving a Design
- Designing Something New

B. *Procedures as Designs*
- Analyzing a Procedure
- Evaluating a Procedure
- Improving a Procedure

A potentially important finding is that experts spend more time than novices in what might be called preliminary activities: conceptualizing a problem, finding alternative ways of representing it, and planning an approach (Larkin, McDermott, Simon and Simon, 1980; Schoenfeld, 1980). Not surprisingly, in view of this finding, programs that focus on heuristics typically put considerable emphasis on conceptualizing, representation, and planning activities.

Examples of heuristics-oriented approaches include the *Productive Thinking* program of Covington and others (1974), Schoenfeld's (1980) approach to teaching problem solving in mathematics, and the *Patterns of Problem Solving* course developed by Rubenstein (1975) at the University of California in Los Angeles. The "operations" taught in de Bono's (1983) *CoRT* (Cognitive Research Trust) program might be considered heuristics as the term is used here.

"The Learning Cycle approach to instruction . . . distinguishes three phases of the learning process: exploration, invention, and application."

Formal Thinking or Stage Development

Few psychologists have had as profound an impact on developmental and educational psychology in recent years as Jean Piaget. Especially influential has been his belief that cognitive development occurs in stages and that the ability to perform formal or abstract operations normally is acquired only after the ability to perform concrete operations. We have already noted that several recent studies have revealed that many high school graduates arrive at college without the ability to engage in the kind of abstract thinking that their college experience will require of them. From the Piagetian perspective, these students appear to be stuck at the concrete-operations level of cognitive development.

Several programs have been developed to bring such students into the formal-operations stage. A few of them have been designed by college professors to address needs they have encountered in their own teaching. Typically in these cases the teaching of thinking skills is embedded within conventional content courses. Indeed, the approach has been to modify how conventional courses are taught so as to ensure not only that the students are exposed to the appropriate subject matter but that they process it in an active way. A great deal of emphasis is placed on student participation, inquiry, exploration, and hypothesis formation and testing.

Several of these programs represent variations on a common theme. For instance, the Learning Cycle approach to instruction developed by Karplus (1974) and his colleagues distinguishes three phases of the learning process: exploration, invention, and application. During the first of these phases, students engage in relatively nondirected exploratory activities with concrete and specific objects and relationships. The purpose of this activity is to gather information about particular aspects of the world. During the invention phase, students are encouraged to generalize their concrete experiences and to discover from them principles whose relevance extends beyond the situations explored. During the final phase, students attempt to apply these principles in other contexts. The Piagetian influence is evident in the way in which this approach moves the student from the more specific and concrete to the more general and abstract.

One of the first programs to be implemented using this framework was the ADAPT (Accent on the Development of Abstract Processes of Thought) program, which was developed at the University of Nebraska (Campbell and others, 1980). The program was designed for first-year college students and included courses in anthropology, economics, English, history, mathematics, and physics. Students who wished to participate in ADAPT took all the ADAPT courses. The individual courses were designed by the professors who were normally responsible for those subjects; in effect, this meant redesigning courses with the Learning Cycle in mind. The intent was to make the course material accessible "to the concrete, as well as to the formal student" and to help move concrete students to the formal stage of cognitive development. Several subsequently developed projects have been patterned on the Learning Cycle approach and implemented at the college level.

An example of a program developed by elementary and secondary school teachers that is also focused on facilitating the movement of students from one Piagetian stage of development to a higher one is the Cognitive Matching Levels project in the Shoreham-Wading River school district in New York (Brooks, Fusco, and Grennon, 1983). This project focuses on learning to assess the cognitive levels of individual students in order to match the cognitive demands of their own curriculum materials and classroom techniques to those levels.

Language and Symbol Manipulation

Whatever else thinking is, much of it involves symbol manipulation of one type or another. This includes the writing of prose and the representation of ideas and relationships with nonverbal symbols such as equations. Effective writing is a disciplined activi-

John McNamara

ty requiring an ability to express thoughts clearly as well as coherently. It requires planning and working toward a goal, the decomposition of a task into component subtasks, the integration of partial products into a coherent whole.

Some researchers have felt that it is unlikely that one's language skills, and one's writing ability in particular, can be enhanced without a corresponding improvement in one's ability to think. Conversely, some have been willing to assume that improving writing ability should enhance thinking skills as well. Thus, writing is viewed not only as a medium of thought but also as a vehicle for developing it. Another major advantage of writing as a means for teaching thinking is that it yields a tangible product that can be evaluated.

The idea that thinking can be improved through instruction in writing has been promoted more in books than in programs; for instance, *Confront, Construct, Complete* (Easterling and Pasanen, 1979); *The Little Red Writing Book* (Scardamalia and others, 1979); *Rhetoric: Discovery and Change* (Young, 1970); and *Student-Centered*

"Thinking is a totally knowledge-dependent activity; to think, one must think *about something*."

Language Arts and Reading (Moffet and Wagner, 1976).

Also of special interest to researchers is the problem of writing computer programs. Like the writing of prose, computer programming may be considered prototypical of many cognitively demanding goal-oriented tasks. It involves planning, anticipating, problem decomposition, hypothesis generation and testing, and numerous other activities and ideas generally applicable to a broad range of problem domains (Nickerson, 1983).

Among the best known efforts to use programming as a vehicle for teaching thinking skills are those that have centered on the use of LOGO—a computer language designed explicitly for use by children as young as primary school age. The use of LOGO to teach—or help students discover—procedural mathematics has been promoted most actively by Papert (1980). The attractiveness of the approach stems from the assumption that in learning to program (instruct) a device (a computer-controlled turtle) to move about in certain ways, drawing out figures by leaving a trace of specified segments of its path, the student is not so much learning mathematics as learning to think like a mathematician. Papert and others have argued that in learning to program such a device one learns skills and concepts that are useful to thinking outside the domain of mathematics as well.

Thinking About Thinking

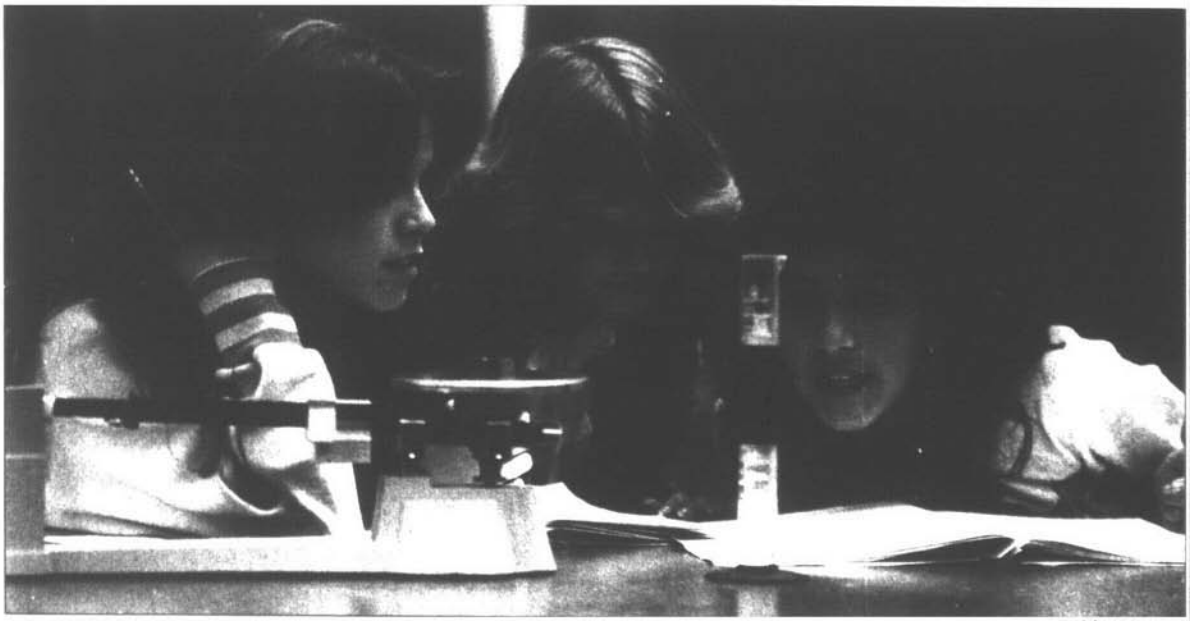
Yet another approach to the teaching of thinking has focused explicitly on thinking as subject matter. The assumption in this case is that learning *about* thinking can improve thinking. Research has revealed a variety of ways in which our thinking is commonly less than optimal (Nisbett and Ross, 1980; Tversky and Kahnemann, 1974; Wason, 1974). Presumably, awareness of the strengths and weaknesses of human beings as thinkers, and in particular of the specific types of reasoning errors that we commonly make, should help us exploit our strengths, compensate for weaknesses, and avoid the more egregious common errors.

One program that explicitly encourages students to think about thinking is the *Philosophy for Children* program developed at Montclair State College (Lipman, Sharp, and Oscanyan, 1980). The design of the program and its material are greatly influenced by the assumption that children have a natural curiosity about the world, about themselves, and—importantly—about their minds and how they work. The challenge to teachers, given this point of departure, is to feed that curiosity and not stifle it. The classroom approach involves engaging students in discussions of a variety of topics related to thinking: the process of inquiry, figuring things out, what a generalization is, causes and effects, and so on.

Closely related to the teaching of thinking as subject matter is the recent interest among researchers in metacognition and the teaching of metacognitive skills. Metacognition is cognition about cognition, knowledge about knowledge, thinking about thinking. According to certain studies, one major difference between expert and novice problem solvers is that the performance of experts has more metacognitive aspects than that of novices. Experts plan more effectively, monitor performance more carefully, and have a greater sense of their own capabilities and limitations as they relate to the problem domain. Although I know of no formal program that focuses exclusively on the teaching of metacognitive skills, research on the question of their teachability is yielding promising results; and several of the programs mentioned above contain metacognitive components.

Learning Strategies

While learning is not synonymous with thinking, the two concepts are sufficiently closely related that it seems appropriate to mention work on the teaching of learning strategies in this paper. Some attention has been given in recent years to the question of whether students can be taught to be more effective learners. Laboratory studies have investigated the effectiveness of specific strategies aimed at improving rote learning or comprehension and retention of meaning.



John McNamara

Evidence regarding the effectiveness of mnemonic strategies for enhancing the ability to retain paired-associates (dates of historical events, capitals of countries, foreign language vocabulary) or lists of items (bones of the body, U.S. presidents, major rivers) is compelling (Baddeley, 1982; Bower, 1970). Emphasizing such techniques in school is a controversial matter, centering not on the question of whether they work—they demonstrably do—but on whether memorization and rote learning should be encouraged. Naysayers argue that an emphasis on these kinds of skills is antithetical to the development of thinking ability.

My own view is that it is a matter of balance. Mnemonic techniques can be useful; and their acquisition should not be threatening to the development of other intellectual abilities unless classroom methods (including testing) stress memorization to the exclusion of comprehension, reasoning, inquiry, exploration, and other higher level skills. With the proper emphasis on a full complex of cognitive skills, the use of mnemonic techniques could enhance the development of complementary abilities rather than inhibit them.

Among the strategies for enhancing comprehension and the retention of meaning that have been investigated are underlining, summarizing, notetaking, paraphrasing, elaborating, diagramming, networking, and others (Nickerson, Salter, Shepard, and Herrnstein, 1984). Also considered as learning strategies are metacognitive strategies for monitoring comprehension and performance, for maintaining attention, and for controlling anxiety, especially in test-taking situations.

One noteworthy effort to implement a program to teach a variety of learning strategies in a coordinated way is that of Weinstein and her colleagues at the University of Texas, which has led to a three-credit course in learning strategies (Underwood, 1982; Weinstein and Underwood, 1983). As a consequence of taking the course students should:

(1) be able to monitor and modify their use of learning strategies; (2) increase their ability to use effective learning strategies; and (3) be able to reduce the stress and negative affect often associated with academic tasks (Weinstein and Underwood, 1983).

Thinking Skills and Knowledge

The acquisition of thinking skills has sometimes been contrasted with the acquisition of knowledge, but the two are clearly not in opposition. Thinking is a totally knowledge-dependent activity; to think, one must think *about something*. Other things being equal, the more one knows, the more effective one's thinking is likely to be. Much knowledge does not guarantee effective thinking, but lack of knowledge surely prohibits it. We cannot think effectively about physics, or politics, or baseball unless we know something about physics, politics, or baseball. In general, our ability to deal effectively with the intellectually demanding problems that we encounter in life is as constrained by the lack of specific knowledge germane to those problems as it is by the inadequacy of our general reasoning and problem-solving skills. Knowledge and thinking ability are interdependent and mutually reinforcing; attempting to develop one without the other is like trying to make cloth with only one side.

Do Programs To Teach Thinking Work?

Evidence regarding the effectiveness of specific programs for teaching thinking is sparse. This may be the result of a variety of factors: these programs are new; and there has not yet been time to evaluate them properly; educational evaluation is inherently difficult, and its results are seldom unequivocal; program developers have sometimes been sufficiently convinced of the merits of their approach that they have not been motivated to attempt an evaluation themselves.

The evaluation data that do exist are neither sufficiently extensive nor sufficiently robust to conclude that any given approach is either much better or much poorer than all the others. Moreover, it is difficult to make evaluative comparisons across programs because the programs differ considerably in terms of the contexts for which they would be appropriate. Quantitative data on a few programs indicate that they produce modest improvements in performance on a variety of tests of mental ability. They make it clear that no one can yet assure the development of effective thinking skills in the classroom, but they reinforce the conviction that the goal is a reasonable one and that progress is being made in its pursuit.

Putting greater emphasis on the teaching of thinking skills in the classroom is a healthy development in U.S. schools. It should be recognized, however, that the quest is an ambitious one and that a great deal of experimentation will be required before truly satisfactory results can be obtained.□

References

Baddeley, A. *Your Memory: A User's Guide*. New York: Macmillan, 1982.

Bower, G. H. "Organizational Factors in Memory." *Cognitive Psychology* 1 (1970): 18–46.

Brooks, M.; Fusco, E.; and Grennon, J. "Cognitive Levels Matching." *Educational Leadership* 40 (May 1983): 4–8.

Campbell, T. C.; Fuller, R. G.; Thornton, M. C.; Peter, J. L.; Peterson, M. Q.; Carpenter, E. T.; and Narveson, R. D. "A Teacher's Guide to the Learning Cycle. A Piagetian-Based Approach to College Instruction." In *Piagetian Programs in Higher Education*. Edited by R. G. Fuller and others. Lincoln, Nebr.: ADAPT, University of Nebraska-Lincoln, 1980.

Carpenter, E. T. "Piagetian Interviews of College Students." In *Piagetian Programs in Higher Education*. Edited by R. G. Fuller and others. Lincoln, Nebr.: ADAPT, University of Nebraska-Lincoln, 1980.

Carpenter, T. P.; Corbitt, M. K.; Kepner, H.; Lindquist, M. M.; and Reys, R. W. "Problem Solving in Mathematics: National Assessment Results." *Educational Leadership* 37 (1980): 562–563.

Clement, J. "Students' Preconceptions in Introductory Mechanics." *American Journal of Physics* 50 (1982): 66–71.

Covington, M. V.; Crutchfield, R. S.; Davies, L.; and Olton, R. M. *The Productive Thinking Program: A Course in Learning to Think*. Columbus, Ohio: Merrill, 1974.

de Bono, E. "The Cognitive Research Trust (CoRT) Thinking Program." In *Thinking: The Expanding Frontier*. Edited by W. Maxwell. Philadelphia: The Franklin Institute Press, 1983.

Easterling, J., and Pasanen, J. *Confront, Construct, Complete*. Rochelle Park, N.J.: Hayden Publishing Company, 1979.

Feuerstein, R.; Rand, Y.; Hoffman, M. B.; and Miller, R. *Instrumental Enrichment: An Intervention Program for Cognitive Modifiability*. Baltimore, Md.: University Park Press, 1980.

Gagne, R. *Science—A Process Approach: Purposes, Accomplishments, Expectations*. Commission on Science Education, Association for the Advancement of Science, 1967.

Karplus, R. *Science Curriculum Improvement Study Teachers Handbook*. Berkeley: University of California, 1974.

Larkin, J. H.; McDermott, J.; Simon, D. P.; and Simon, H. A. "Expert and Novice Performance in Solving Physics Problems." *Science* 208 (1980): 1335–1342.

Lipman, M.; Sharp, A. M.; and Oscanyan, F. *Philosophy in the Classroom*. Philadelphia: Temple University Press, 1980.

McCloskey, M.; Carmazza, A.; and Green, B. "Curvilinear Motion in the Absence of External Forces: Naive Beliefs About the Motion of Objects." *Science* 210 (1980): 1139–1141.

Meeker, M. N. *The Structure of Intellect: Its Interpretation and Uses*. Columbus: Charles E. Merrill, 1969.

Moffet, J., and Wagner, B. J. *Student-Centered Language Arts and Reading K-13: A Handbook for Teachers*. 2nd ed. Boston: Houghton Mifflin Co., 1976.

Nickerson, R. S. "Computer Programming as a Vehicle for Teaching Thinking Skills." *Journal of Philosophy for Children* 4 (1983): 42–48.

Nickerson, R. S. *Understanding Understanding* (BBN Report No. 5087).

Nickerson, R. S.; Perkins, D. N.; and Smith, E. E. *Teaching Thinking* (BBN Report No. 5575), in press.

Nickerson, R. S.; Salter, W.; Shepard; and Herrnstein, J. *The Teaching of Learning Strategies* (BBN Report No. 5578), 1984.

Nisbett, R., and Ross, L. *Human Inferences: Strategies and Shortcomings of Social Judgment*. Englewood Cliffs, N.J.: Prentice-Hall, 1980.

Papert, S. *Mindstorms*. New York: Basic Books, 1980.

Polya, G. *How to Solve It*. Princeton, N.J.: Doubleday, 1957.

Renner, J. W., and Lawson, A. E. "Promoting Intellectual Development Through Science Teaching." *The Physics Teacher* 11 (1973).

Rubenstein, M. F. *Patterns of Problem Solving*, Prentice-Hall, 1975.

Scardamalia, M.; Bereiter, C.; and Fillion, B. *The Little Red Writing Book: A Source Book of Consequential Writing Activities*. Ontario, Canada: Pedagogy of Writing Project, 1979.

Schoenfeld, A. H. "Teaching Problem-Solving Skills." *American Mathematical Monthly* 87 (1980): 794–805.

Tomlinson-Keasey, C. "Formal Operations in Females Aged 11 to 54 Years of Age." *Development Psychology* 6, 364 (1972).

Trowbridge, D. E., and McDermott, L. C. "Investigation of Student Understanding of the Concept of Velocity in One Dimension." *American Journal of Physics* 48, 12 (1980): 1020–1028.

Tversky, A., and Kahneman, D. "Judgment Under Uncertainty: Heuristics and Biases." *Science* 185 (1974): 1124–1131.

Underwood, V. L. "Self-Management Skills for College Students: A Program in How to Learn." Doctoral dissertation, University of Texas, 1982.

Wason, P. C. "The Psychology of Deceptive Problems." *New Scientist* 63 (1974): 382–385.

Weinstein, C. E., and Underwood, V. L. "Learning Strategies: The *How* of Learning." In *Relating Instruction to Basic Research*. Edited by J. Segal, S. Chipman, and R. Glaser. Hillsdale, N.J.: Lawrence Erlbaum Associates, 1983.

Young, Richard E., and others. *Rhetoric: Discovery and Change*. Harcourt, Brace and Jovanovich, Inc., 1970.