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ABSTRACT

This discussion of some of the research literature that is relevant to the issue of teaching thinking provides descriptions of hypothetical, ideal thinkers, and problem solvers; considers the problem of teaching thinking and problem solving; and explores the issue of evaluating programs so that they can be revised and improved. Following Bransford and Stein's "The IDEAL Problem Solver" (1984), this discussion elaborates upon five components of thinking that are applicable to a wide variety of situations. These include the ability to: (1)identify problems, (2) define and represent them with precision, (3) explore possible strategies, (4) act on these strategies, and (5) look at their effects. Creativity is introduced as a means of re-defining a problem in such a way as to suggest simpler and more workable strategies, and examples of cognitive solutions to problems are explained. Also included are descriptions of ways to enhance the teaching of thinking and problem solving through the use of educational strategies and the development of conceptual tools. The concluding section contains suggestions for implementing evaluation techniques for thinking skills programs, and the summary emphasizes the importance of student use of various tools for thinking and problem solving so that these can be evaluated and defined. (JB)

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Teaching Thinking and Problem Solving

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Teaching Thinking and Problem Solving[1]

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There are no simple solutions;

only intelligent choices.

There are several ways that the preceding quotation is relevant to educators. First, it emphasizes the need to help students become independent thinkers and problem solvers. Second, it reminds us that there is no simple procedure for achieving such a goal. We need to make intelligent choices each step of the way.

In this paper we discuss some of the research literature that is relevant to the issue of teaching thinking. In particular, we:

1. provide descriptions of hypothetical, ideal thinkers and problem solvers;

2. discuss the problem of teaching thinking and problem solving;

3. explore the issue of evaluating programs so that they can be revised and improved.

1.0 The IDEAL problem Solver

During the past ten years there has been a great deal of research on the processes that underlie effective thinking and problem solving.[2] Our discussion of the issue will follow Bransford and Stein's The IDEAL Problem Solver (1984).[3] They emphasize five components of thinking that are applicable to a wide variety of situations. These include the ability to Identify problems, Define and represent them with precision, Explore possible strategies, Act on these strategies and Look at the effects. Note that the first letter of each of these components is found in the word IDEAL. In the discussion below, we examine each of these components in more detail.

1.1 I = Identification of Problems

The ability to identify the existence of problems is one of the most important characteristics of successful problem solvers. In business, for example, it can mean the difference between failure and success. In his book Getting Things Done, Bliss notes that leaders of a company in Britain discovered that they were requesting a great deal of paper work from their employees that was unnecessary.[4] Employees had to fill out cards on each item that was sold in order to keep track of inventory, and they were required to complete daily time cards indicating the number of hours worked. Within one year after the problem of excessive paper work had been discovered, 26 million cards and sheets of paper had been eliminated. Obviously, a solution to this problem would never have been generated if the problem had not been identified in the first place.

Problem identification is important in academic settings as well as in business. As an illustration, assume that young students work with a computer simulation that includes a farmer who wants to fence a small lot. The farmer measures the lot by counting the number of steps necessary to walk around it and then goes to a hardware store and orders 80 "feet" of fence. Ideally, even the young problem solver will notice that this measurement process will probably lead to error if the farmer wants to buy exactly the right amount of fencing.

As another example of problem identification, assume that an IDEAL problem solver is reading a text and confronts a statement such as "The notes were sour because the seam split". Unlike a less effective learner who may simply be going through the motions of reading while actually daydreaming, the effective learner will realize that a problem exists (i.e., the statement does not make sense). If the problem is not identified, possible strategies such as rereading and asking questions of clarification will not be tried.

Whimbey provides an example that illustrates the importance of problem identificaiton for reading comprehension. He presented the following passage to college students who were poor readers:[5]

> If a serious literary critic were to write a favorable, full-length review of How Could I Tell Mother She Frightened My Boyfriends Away, Grace Plumbuster's new story, his startled readers would assume that he had gone mad, or that Grace Plumbuster was his editor's wife.

Whimbey notes that, when he first read the paragraph, he had to stop and reread it several times in order to comprehend its meaning. In contrast, many poor readers simply continued to read without realizing the existence of a comprehension problem that needed to be solved.

1.2 D = Definition of Probelms

Once a problem has been identified it must be defined with more precision. People can agree that a problem exists yet differ in how they define it, and their definitions of problems can have important effects on the types of solutions that are tried. For example, a number of educators have identified a problem with many school systems; namely, that they are not helping students become effective thinkers. Although we may all agree that such a problem exists, there are many different ways to define it. The problem may be due to poor teachers and hence might be solved by increasing admission standards in college, paying teachers more money and so forth. Others might define the problem as due to poor curriculum materials and still others might define it as a lack of knowledge about what we mean by thinking. Of course, each of these definitions of the problem could have some degree of truth to them. For present purposes, the important point is that different definitions of a problem lead to different solution strategies. For example, the strategy of increasing teacher's pay is different from the strategy of encouraging more research on the teaching of thinking. Similarly, a strategy such as creating special science and mathematics schools for high achieving students reflects a definition of the problem that emphasizes the need for a few thousand highly trained people rather than the need to increase everyone's problem solving skills.

Differences in problem definition can have strong effects on people's abilities to think and solve problems. The history of science contains many examples of scientists who were more successful than their predecessors because they defined problems in more fruitful ways. Copernicus provides an interesting illustration.[6] He eventually solved a problem that others before him had failed to solve: How to account for the movement of the planets in the heavens. Astronomers had collected data indicating where various planets were at particular points in time (e.g., during different months). Nevertheless, no one had been able to come up with a theory of their orbits that predicted where they should appear and that explained why.

After years of study, Copernicus finally created a theory that predicted the movements of the planets. In order to do so, he had to make a radical assumption. Prior to Copernicus, everyone had taken it for granted that the sun and other planets revolve around the earth--and indeed, it looks that way to the naked eye. Copernicus argued that, if one made this assumption, it would be impossible to predict with accuracy the movement of the planets. His theory began with an alternate assumption;

namely, that the earth and other planets in our solar system revolve around the sun. Note that Copernicus' predecessors had implicitly defined their problem as "Why do the planets move as they do given that the earth is the center of the Universe?" Copernicus eventually defined the problem differently and only then was able to achieve success.

Earlier in this chapter we defined a problem as "Why are school systems not helping students become effective thinkers"? This definition of the problem involves the assumption that it is the school system that is solely responsible for the poor training in thinking--an assumption that may render the problem impossible or at least much more difficult to solve. An alternate approach to developing thinking and solving skills is to assume that society as a whole guides thinking and to enlist the support of a number of different factions in our society rather than focus only on schools. For example, parents could be encouraged to emphasize thinking and problem solving, businesses could provide information about the importance of problem solving in the workplace, cultural heroes and heroines such as sports figures and movie stars could support the effort and so forth. By defining problems too narrowly (e.g., by assuming that only schools are responsible for increasing problem solving), we place unnecessary limits on the strategies for solution that we employ.

Problem definition is closely related to the representation of problems. If you represent a problem by writing "What is 2/5 of 1/2?", for example, you will probably begin to multiply the fractions. However, if you represent the problem as "What is 1/2 of 2/5?", a much simpler strategy for solution usually comes to mind.

The units of measurement that we employ also reflect different definitions of problems. If you are in the business of transporting large groups of people you will face questions about fuel efficiency. For this type of business, the problem of fuel efficiency will probably be defined in terms of passenger miles per gallon (where buses are more efficient than cars) rather than miles per gallon (where cars are more efficient than buses). Thus, a particular unit of measurement may or may not be appropriate depending on the problem one is trying to solve.

Different manufacturers often adopt particular units of measurement that influence how people think about various products. Thus, one manufacturer of computers might argue that its product is the most efficient in terms of "cost per kilobyte of memory." A second manufacturer might emphasize the importance of "cost relative to the amount of quality software available," a third might emphasize "cost relative to the ease of learning about the system." It seems clear that these different ways of thinking about computers can have strong effects on the decisions that potential purchasers eventually make.

1.3 E = Exploration of Strategies

It is clear that the ability to identify and define problems provides no guarantee of a successful solution. IDEAL problem solvers explore a variety of strategies that can help them succeed. Several examples of successful strategies are provided below.

1.3.1 Breaking problems into manageable sub-problems

One general strategy that is characteristic of effective problem solvers is to break complex problems into sub-problems that are more manageable. People who fail to do this frequently conclude that complex problems are impossible to solve.

A mother who was enrolled in one of our problem solving courses supplied the following example. Her child decided that she could not learn to spell the word "Tennessee" because it was too complex. The mother helped her child break the problem into simpler sub-problems by focusing on the spelling of "ten", "nes", and then "see".

Earlier in this chapter (see the section on problem identification), we used the following passage to illustrate the importance of identifying comprehension problems:[7]

> If a serious literary critic were to write a favorable, full-length review of How Could I Tell Mother She Frightened My Boyfriends Away, Grace Plumbuster's new story, his startled readers would assume that he had gone mad, or that Grace Plumbuster was his editor's wife. (p. 85)

It seems clear that a reader could identify a problem with his or her comprehension of the passage, define the problem as being due to processing difficulties (as opposed to insufficient information in the passage, for example) and yet still fail to comprehend the passage. Without strategies that attempt to break the overall passage into comprehensible subunits, it is doubtful that anyone could understand what the author intended to say.

1.3.2 The Use of Special Cases

In addition to the strategy of breaking complex problems into manageable parts, another general strategy is to solve a problem by first looking at a special case. As an illustration, assume that a manager of a health club focuses on a sub-problem such as the following:[8]

> A racquetball tournament will be held at the Manager's Club. One hundred and six people have entered the open single elimination tournament (after losing once the player is eliminated). If the manager needs a score card for each match, how many cards will she need if each player shows up?

This is not an easy problem for most people. One way to solve the problem is to program a hypothetical tournament on a computer. In order to do so, however, you may first need to imagine a special case where only two are enrolled in the tournament. You would then require only one scorecard. If three people were enrolled you would need two scorecards and so forth. It is possible to derive a general rule to determine the number of matches that will be played in such tounaments by examining a few simple cases (number of matches = number of players - 1). This general rule can then be used to solve the problem for a tournament involving 106 players (the answer is 105).

1.3.3 Working Backwards

A third general strategy that is useful involves working backwards on a problem. Bransford and Stein provide the following example:[9]

> It is 4:00 p.m. and you have just received notification that you are expected for an important company meeting in Chicago at 8:00 a.m. the next morning. There are two flights open. One is a dinner flight that leaves a 6:00 p.m. and arrives in Chicago at 6:00 a.m. the next day. The other flight departs at 7:30 p.m. and arrives in Chicago at 7:30 a.m. the next day. When you arrive in Chicago you will need to wait 20 minutes for your luggage and it will take 20 minutes by taxi to get to your meeting. Which flight should you take?

For this problem, an effective strategy is to begin with your goal, which is to be at a meeting in Chicago at 8:00 in the morning, and to work backwards. If you do this, you will see that you need to take the earlier flight.

Working backwards is also useful for many other problems. On tests of reading comprehension, for example, students are usually presented with passages to read and are then required to answer questions about them. An effective strategy on these tests is often to work backwards by first reading the questions and then reading the passages with the questions in mind.

1.3.4 Additional Strategies

There are many additional strategies that are used by effective problem solvers; strategies such as using images and mnemonics in order to remember information, looking for implicit assumptions in one's definitions of problems, searching for inconsistencies in arguments and so forth. In *The IDEAL Problem Solver*, Bransford and Stein (1984) argue that the most important strategy for improving problem solving is to learn about new concepts, theories, and procedures. These can then function as conceptual tools that enable one to perform activities that otherwise would be difficult and perhaps even impossible to perform. However, an understanding of how concepts and principles can function as conceptual tools is quite different from the mere memorization of factual content. The issue of developing conceptual tools is discussed in more detail in the section on teaching thinking and problem solving skills.

1.4 A & L = Acting on Ideas and Looking at the Effects

The fourth and fifth components of the IDEAL problem solving framework are to *act* on the basis of a strategy and *look* at the effects. If people simply think about possible strategies without attempting to actively apply them, they deprive themselves of information that can help them identify unforeseen problems with their old modes of thought.

Imagine that a group of students is studying for an essay test. All students may identify and define their problem and select study strategies. Nevertheless, successful students will also act on the basis of a study strategy and look at the effects before actually taking the test. For example, successful students may select a study strategy and then test its effectiveness by attempting to recall the information while writing practice essays. Failures in such endeavors provide new opportunities for learning. In contrast, the student who fails to act and look has no idea that new problems exist that need to be solved.

Attempts to conduct scientific experiments represent excellent examples of the importance of the act and look components of the IDEAL framework. Students often believe that the ideal experiment is one that confirms existing hypotheses. In contrast, researchers realize that experiments are often valuable because they make apparent the existence of problems that previously were unrecognized. Without active attempts to experiment, problems with existing methods and theories would often fail to be noticed, and the ability to learn would be impaired.

1.5 The IDEAL Cycle and Creativity

Note that the preceding discussion emphasizes the importance of problem solving cycles. After acting and looking one may identify the existence of a new problem, then define it, explore strategies, act on the basis of these new strategies, and look at the effects. This cycle may be repeated until no new problems are identified. In this case one can exit the IDEAL cycle and do something else.

The IDEAL cycle can be illustrated by imagining students who complete a mathematical word problem and come up with the anwer that someone works 36 hours per day. Effective problem solvers will identify the existence of a problem with this answer; namely, that it cannot be correct. The problem may then be defined as being due to an error in calculations. Effective problem solver will then act on the strategy and look at the effects. If the answer still looks incorrect (e.g., it still comes out as 36 hours per day), this again signals the existence of a problem and the IDEAL cycle will be reentered. This time the problem may be redefined as due to a misreading of the word problem rather than an error in calculation, and this change in problem definition should prompt the exploration of new sets of strategies (e.g., carefully reread the entire problem). The effective problem solver will then act on a strategy and look at the effects. If the answer now seems reasonable, the problem solver can exit the IDEAL cycle and do something else.

Different ways of entering the IDEAL cycle can result in strategies that vary in creativity. The creative person who reenters the IDEAL cycle will often re-define a problem in a way that suggests simpler and more workable strategies. As an illustration, consider an example from Adam's book Conceptual Blockbusting.[10] He notes that a group of engineers was trying to design an improved method for mechanically picking tomatoes that would be less likely to bruise them. Their implicit definition of the problem was: "How can we design a mechanical picker that will keep from bruising tomatoes?" Given this definition of the problem, suggestions for strategies included ideas such as putting more padding on the picking arms, slowing the speed of the picking arm and so forth. A different definition of the problem, and one that is quite creative, is "How can we keep tomatoes from getting bruised while they are being picked mechanically?" This definition of the problem led to solutions such as developing a new strain of tomatoes that had slightly stronger skins and that grew further out on the tomato vine.

In his book New Think, de Bono distinguishes between vertical thinking (proceeding systematically from a single concept or definition) and lateral thinking (seeking alternate ways of defining or interpreting a problem). He states:

> Logic is the tool that is used to dig holes deeper and bigger, to make them altogether better holes. But if the hole is in the wrong place, then no amount of improvement is going to put it in the right place. No matter how obvious

this may seem to every digger, it is still easier to go on digging in the same place than to start all over again in a new place. Vertical thinking is digging the same hole deeper; lateral thinking is trying again elsewhere.[11]

De Bono's comments suggest that an important aspect of creative problem solving is to ask ourselves whether we are making implicit assumptions about the nature of a problem that are limiting our ability to find solutions.

A friend of ours was able to creatively redefine a problem that involved the purchase of software for his three-year-old daughter. He first evaluated the degree to which various programs were appropriate for his daughter to use by herself and concluded that, in most instances, the answer was no. For example, one program projected patterns that, over time, gradually produced the image of an animal such as a sheep or dog. The person using the computer was supposed to hit the "escape" key as soon as he or she could identify the figure. The next step was to type in the name of the figure (e.g., dog); the computer would show a clear image of the figure if the answer was correct. Our friend's daughter became very good at this program and had no trouble finding the escape key and pressing it. Nevertheless, she did not yet know how to spell and hence could not work the program without adult supervision.

If our friend had restricted the definition of his problem to "find available software that my daughter can use by herself" he would have had to reject the program involving the recognition of animals. He eventually redefined the problem as "How can I create contexts that make existing programs suitable for use by my daughter?" This led to the strategy of finding pictures of various animals and printing their names under them. The daughter was than taught how to refer to this sheet to determine the correct spelling of animal names. Our friend's daughter was readily able to use the sheet and, in a short amount of time, learned to spell the names of a number of animals without having to refer to the sheet. Overall, our friend's redefinition of the problem led to the creation of an exciting context within which learning occurred.

2.0 TEACHING THINKING AND PROBLEM SOLVING

Our goal in the preceding section was to describe some characteristics of ideal thinkers and problem solvers. Descriptions such as these are useful for clarifying desired end states but they provide little information about how to get there. In this section we explore some of the research literature that is relevant to issues of teaching thinking and problem solving.

2.1.1 Access and the Problem of Inert Knowledge

At first glance the problem of teaching thinking and problem solving is straightforward: Provide students with information about effective thinking and problem solving and make sure that this information is learned. Shortcomings of this approach involve the problem of access. The fact that people can remember information provides no guarantee that it will be utilized when it is needed.

As a simple illustration of the preceding argument, consider the problem of comprehending statements such as "The haystack was important because the cloth ripped" and "The notes were sour because the seam split."[12] Most people have difficulty comprehending these statements, but not because they lack the knowledge necessary to do so. Instead, the

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problem is that they fail to activate relevant knowledge that people have already acquired. When given prompts that provide them access to relevant information (e.g., "parachute" and "bagpipes," respectively), the preceding statements become easy to comprehend.

The statements about the haystack and the notes are trick sentences, of course. An important component of the art of creating trick sentences and problems involves the ability to phrase things in a way that will cause otherwise competent people to fail to access information that they already know. We know of no educators who are so devious that all of their lectures and tests are composed of trick questions. Nevertheless, there appear to be many instances where students fail to access information that they have learned. Many years ago, Alfred Whitehead warned about the dangers of inert knowledge--knowledge that is accessed only in a restricted set of contexts even though it is applicable to a wide variety of domains.[13] He also argued that traditional educational practice tended to produce knowledge that remained inert.

A study conducted by Gick and Holyoak provides an informative illustration of the problem of inert knowledge.[14] They had college students memorize the following story about a military campaign.

> A general wishes to capture a fortress located in the center of a country. There are many roads radiating outward from the fortress. All have been mined so that while small groups of men can pass over the roads safely, a large force will detonate the mines. A full-scale direct attack is therefore impossible. The general's solution is to divide his army into small groups, send each group to the head of a different

road, and have the groups converge simultaneously on the fortress.

After the students had successfully recalled the military problem and its solution, they were given Duncker's Radiation Problem to solve.[15]

Suppose you are a doctor faced with a patient who had a malignant tumor in his stomach. It is impossible to operate on the patient, but unless the tumor is destroyed the patient will die. There is a kind of ray that may be used to destroy the tumor. If the rays reach the tumor all at once and with sufficiently high intensity, the tumor will be destroyed. At lower intensities the rays are harmless to healthy tissue, but they will not affect the tumor either. What type of procedure might be used to destroy the tumor with the rays, and at the same time avoid destroying the healthy tissue?

This problem can be solved in much the same way as the general solved the Military Problem. In particular, in the Radiation Problem many sources of less intense radiations could pass safely through the healthy tissue and converge on the tumor in sufficient intensity to destroy it.

Because subjects in the Gick and Holyoak study memorized the Military Problem, they presumably had knowledge that could be applied to the Radiation Problem. In fact, 90% of the students were able to use information from the military story to help solve the Radiation Problem given that they received the hint that the prior story was useful.

However, if no hint was given, only 20% of the subjects spontaneously used the military story. For those students who were not given a hint, the information they memorized in the context of the military story therefore remained inert.

Studies conducted by Perfetto, Bransford and Franks provide additional evidence that relevant knowledge can remain inert even though it is potentially useful[16]. They presented college students with a series of "insight" problems such as the following:

1. Uriah Fuller, the famous Israeli superpsychic, can tell you the score of any baseball game before the game starts. What is his secret?

2. A man living in a small town in the U.S. married twenty different women in the same town. All are still living and he has never divorced one of them. Yet, he has broken no law. Can you explain?

Most college students have difficulty answering these questions unless provided with hints or clues. Prior to solving the problems, some students were given clue information that was obviusly relevant to each problem's solution. Thus, these students first received statements such as "Before it starts the score of any game is 0 to 0"; "A minister marries several people each week." The students were then presented with the problems and explicitly prompted to use the clue information (which was now stored in memory) to solve them: Their problem-solving performance was excellent. Other students were first presented with the clues and then given the problems but they were not explicitly prompted to use the clues for problem solution. Their problem solving performance was very poor; in fact, it was no better than that of baseline students who never received any clues.

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The Perfetto et al. results represent an especially strong demonstration of access failure (i.e., of inert knowledge) because the clues were constructed to be obviously relevant to problem solution. Indeed, the authors noted that, before conducting the experiment, they expected even the uninformed students to spontaneously access the correct answers because of the obvious relationship between the problems and the clues.

Most instructors have experienced situations where students fail to utilize relevant concepts and procedures. In classes on problem solving, for example, we frequently find situations where students are capable of analyzing faulty arguments when explicitly prompted yet they fail to do so spontaneously. Thus, they may fail to spontaneously recognize that an argument is based on a faulty analogy, or they may commit an error such as assuming that correlation implies causation despite knowing better. In short, students are frequently able to think about various concepts and procedures but they do not necessarily think with them. A challenge for educators is to help students transform facts and procedures that they can describe and think about into useful conceptual tools.

2.1.2 The Development of Conceptual Tools

A number of theorists argue that it is particularly important for people to understand how concepts and procedures can function as tools that enable them to solve a variety of problems. Bacon emphasized this idea long ago when he discussed the importance of "mental helps".

> The unassisted hand and the understanding left to itself possess but little power. Effects are produced by means of instruments and helps,

which the understanding requires no less than the hand.[17]

The idea of powerful sets of "helps" or tools for enhancing problem solving seems to be very important. Based on our experiences, few students view their courses from this perspective. For example, we have asked a number of college students majoring in education or arts and science to explain why logarithms are useful. In what ways do they make it easier to solve various problems? Despite remembering something about logarithms, the vast majority of the students were surprised when told that logarithms represent an important invention that greatly simplifies problem solving. They had never been helped to understand logarithms in the way illustrated by the following quotation from the English Mathematician Henry Briggs (1624):

> Logarithms are numbers invented for the more easy working of questions in arithmetic and geometry. By them all troublesome multiplications are avoided and performed only by addition....In a word, all questions not only in arithmetic and geometry but in astronomy also are thereby most plainly and easily answered.[18]

We have encountered many additional examples of situations where students have memorized facts and theories with very little appreciation of how they make it possible to solve otherwise-perplexing problems. For example, many young children feel that it would be easier if there were only one unit of measurement such as "inches" rather than multiple units such as "feet", "yards" and "miles". With one unit of measurement, there is less that needs to be learned. The children are correct to some extent, but they fail to appreciate how different units of measurement provide tools that greatly simplify problem solving. Thus, it would be extremely cumbersome to measure the distance between Connecticut and Tennessee in terms of inches. Frequently, we fail to help students appreciate the tool function of knowledge. In order to become useful for thinking, facts and procedures must be transformed into conceptual tools.

As a simple illustration of the power of concepts as tools, consider the drawings in Figure 1. By prompting people to activate concepts they have already learned, one can help them conceptualize these drawings in a new manner. The first can be viewed as a bear climbing up the opposite side of a tree and the second as the Eiffel Tower viewed from the inside of an armored car. Note how one understands the drawings differently when they are viewed from these perspectives.

Figure 1 here

The philosopher N. R. Hanson argues that the creation of new scientific theories fulfills an analogous function: It enables people to conceptualize events in new and previously unappreciated ways.[19]

2.1.3 Access Revisited

In the preceding discussion we first introduced perplexing situations and then introduced concepts (e.g. "bagpipes","bears climbing trees") that rendered them less perplexing. What happens when students are told about concepts and principles yet are not helped to understand their function? We argue that they are less likely to access relevant concepts and procedures because they do not understand the kinds of problems that these discoveries were designed to solve. As an illustration, consider once again the example about logarithms. Assume that students are without a calculator or computer and must multiply a number of pairs of large numbers. Unless they had previously learned that logarithms enable one to substitute simple additions for difficult multiplications, it is highly unlikely that they would think of using them in this situation.

In our earlier discussion of experiments by Perfetto et. al we noted that college students did not spontaneously access relevant information even though it had just been presented. For example, students were unable to explain how someone could accurately predict the score of any game before it began despite the fact that, just a few minute earlier, they had learned that "Before it begins, the score of a game is 0 to 0". This information had remained inert.

Imagine a slight change in the learning situation. In the new situation students are presented with statements in the following manner: "It is easy to guess the score of any game before it begins (pause); the score is 0 to 0". This mode of presentation should help students identify and define a problem; namely that, as the pause begins, it is not clear why it should be easy to guess the score of any game. After the pause, the answer "the score is 0 to 0" becomes a tool for solving a problem rather than a mere fact. Initial data from studies at Vanderbilt suggest that, given this latter learning situation, students are much more likely to spontaneously access relevant knowledge when, later, they are given problems to solve.[20] This increase in access is presumably due to the advantages of understanding the kinds of problems that various types of information can help one solve. In a similar manner, studies in which new strategies have been taught report much more transfer when students are helped to understand why and how these strategies can be used.[21]

2.1.4 Teaching Thinking Across the Curriculum

Our approach to teaching thinking emphasizes the importance of helping students analyze their own problem solving processes and to understand how inventions and discoveries enable them to solve important problems. For example, we want to help them understand how the invention of writing systems, number systems, procedures for logical analyses, theories and so forth make it possible for them do things that otherwise might be difficult or impossible. However, it is not sufficient to simply supply students with such information. They need to experience its usefulness for themselves. Furthermore, they need to learn to identify and define situations where various types of knowledge can and should be used.[22]

Students rarely receive the opportunity to practice problem identification and problem definition. For example, assume that we present students with a sample argument and ask them to analyze it for logical consistency. We have identified and defined the problem for them rather than ask whether they would spontaneously do so for themselves. Similarly, we can ask students to define various concepts, but this provides no guarantee that they will spontaneously use them later on.

Recently, we have been experimenting with an approach to teaching thinking that helps students appreciate the functions of concepts and procedures plus permits practice at problem identification.[23] It certainly is not the only way to teach thinking, but it nevertheless seems promising. It might serve as a model for other approaches that one might take.

The approach that we are developing involves analyses of movies--preferably ones that are displayed on videodiscs. Videodisc technology enables us, for the first time, to exercise control over an existing motion picture: to stop it, back it up, go forward in slow motion or one frame at a time, or even search and find specific scenes almost instantaneously. Until now, there was only one way to view a movie--on the filmmaker's terms. In fact, much of the "magic" of movies is derived from their ability to draw us into a new reality and sweep us along with a compelling inertia. Now, with the push of a button, that inertia can be interrupted and the "magic" dispelled by the viewer who says: "Wait a minute, I want to see that stunt in slow motion," or asks: I wonder what kind of spiders they used in that scene, let's take another look."

We are currently using movies rather than educational films that contain lectures. By eliminating the lectures, we create more opportunity for students to discover questions and issues on their own. As an illustration, consider the movie "Raiders of the Lost Ark," an action-packed adventure film directed by Steven Spielberg. When we began to examine a film like "Raiders," we quickly discovered that there were several distinct perspectives that could be brought to the movie. The first is that of the viewer seeing a movie for the first time. The viewer is there to be entertained, to be transported to a fantasy world of exotic times and places, in this case to South America, Nepal and Egypt during the rise of Nazi Germany. For an hour or two, the moviemaker's fantasy becomes the viewer's reality. And a roomful of snakes, something to really worry about.

A second perspective occurs when the viewer's own sense of the real world interfaces with the fantasy of the movie. The critical thinker in us comes out. We notice things that do not make sense. We grimace at dialogue that we think is not believable. Or we just ask questions about the movie: I wonder if there really was an Ark of the Covenant? Are cobras found in Egypt? I thought they were from Asia. Even a first-time viewer may adopt this mind-set, particularly if the movie is a bad one. A viewer who looks at a film over and over is sure to begin asking these kinds of questions.

A third perspective occurs when we become curious about the making of the movie. We become interested in the reality behind the fantasy and in the nature of the problems that the films' actors and directors solved. Did Indiana Jones really whip the gun out of the traitor's hand? How did they do that? That cobra sure looked real, was it? How come it didn't bite the actors?

It is with these last two perspectives in particular that we begin to recognize the vast educational opportunities in a movie like "Raiders of the Lost Ark," opportunities for problem-solving and critical-thinking which are virtually invisible when we see the film the first time. And which are in a wide assortment of subject areas: math, history, chemistry, physics, anthropology, psychology, geography, theatre arts, music, etc. Also, they are not presented in isolation but in the context of the movie, or of movie-making, and are often inter-related and inter-connected with each other. And they are always presented in a multi-sensory way; we can see and hear and sometimes almost feel their nature--thanks to the "magic" of the filmmaking art and craft.

Take, for example, the opening three minutes of "Raiders," a scene set in the steamy jungles of South America. As we listen to the singing of exotic birds and watch the sun's rays pentrating the dense foliage, we follow Indiana Jones, his guides and porters, and witness their encounter first with a statue of some ancient idol, then with a poisoned dart fired by some unseen tribal enemy. If we imagine ourselves as students watching this scene over and over again, we notice that what we "see" expands, and we are filled with observations and questions.

1. Who are these guides? They are caucasian and unkempt. They speak with an accent. (Ans: They are of Spanish descent)

2. Who are these porters wearing knit hats and brightly colored sarapis even in the hot jungle? They have dark Indian features. Where do they come from? (Ans: They are highland Indians, maybe of Inca descent)

3. Why is it that in one scene an Indian leads the mule, and in the next, one of the guides does? (Ans: A discontinuity)

4. Is there hot tropical jungle in Peru? I thought it was a high country in the Andes. (Ans: It has both plus an arid seacoast)

5. What culture worshipped idols such as this? Inca? Some other? Whey did it frighten the Indians? Or was that just to make the movie scary?

6. Is this an authentic statue, or something fabricated for the movie? In either case, how was it made?

7. What kind of people use poisoned darts? What is the

poison? What can be discovered by tasting it? How deadly is it? Do they hunt with darts? How does a blow-gun work? How is it made?

8. The guide tastes the poison and says: "Three days old...still fresh...they are following us." Does this make sense? (Ans: Not really. If they were following, they wouldn't have arrived there yet...to shoot the dart)

It takes little imagination to see how questions like these can lead to exciting inquiries into history, geography, anthropology, physics, chemistry, religion and, of course, movie-making. Furthermore, they all involve actual thinking and problem solving. And they were all generated by only three minutes of the film.

Other segments of "Raiders" provide many additional opportunties to discover and solve problems. For example, at one point in the film Indiana Jones needs to replace a golden idol with a bag of sand so that a trap will not be set into motion. We had watched the movie a number of times before it occured to us to ask whether it was reasonable that a solid gold idol would weigh about the same as a small bag of sand.

Once a problem such as this is identified it provides an excellent context for learning new information. For example, all college students with whom we have worked know that one could determine the weight of an idol by weighing it. However, many did not know how to determine the weight of the idol given that it was unavailable and hence could not be weighed with a scale. Similarly, many could not explain how to estimate the weights of a gold versus lead idol, especially if the two were shaped very differently and hence probably had different volumes. When concepts such as density and the Archimedes principle of measuring volume by water displacement are introduced in such contexts, they become especially meaningful for students. Many students note that they had studied these concepts before but had never understood how they could be used to solve interesting problems.

According to our calculations, a solid gold idol the size of the one in Raiders would weigh approximately 40 pounds, yet the actors are carrying and throwing it with no difficulty. Given such apparent inconsistencies, a number of aspects of reasoning can be discussed. For example, "If the idol were solid gold, it would be very heavy to carry. It clearly is not especially heavy to carry, however, hence it must not be solid gold". Is this argument valid? Why? A number of other aspects of just the first 14 minutes of Raiders provide a host of additional opportunities to identify and define problems, reason about them and so forth. For example, at one point Indiana Jones jumps across a pit. How can one estimate the width of the pit, and could a human actually jump that far (for example, what is the world record in the running broad jump?). In addition, if one were to do experiments in order to determine information about jumping, how would one proceed? Problems such as this provide a context for discussing experimentation, averages, variability in performance and so forth.

At another point in the adventure Indiana and his cohort use torches to light their way. Why did they not use flashlights? At the beginning of the film the date is given as 1936. Was there electricity at this time? Were there batteries at this time, and how portable were they? What guidelines exist for making reasonable inferences about questions such as these?

Overall, videodisc technology--and to a large extent videotape technology--gives us the ability to study a motion picture in much the same fashion that a scientist studies phenomena in the laboratory. The more we look, the more we perceive and understand. And the more we want to know. In short, we can learn from movies even though they are not designed to teach. Maybe that's why they are so effective. There is no discursive educational "set-up" which says: "You are the student, now listen carefully to what I'm going to teach you." Both teacher and student can learn.

As noted earlier, a major advantage of movies is that they provide opportunities to identify and define problems. We find that activities such as these play an important role in transfer. For example, members of our research team now view most films--as well as many segments of everyday life--from a problem solving perspective. Our knowledge about thinking and problem solving is therefore much less inert than it otherwise would have been, hence we continue to learn. It is important to note, however, that an integral part of this learning process involves efforts to analyze and systematize our general processes and strategies.[24]. Without an emphasis on reflection, analysis and systematization, it seems unlikely that powerful transfer will occur. By the same token, students need to be helped to reflect upon the processes they use to identify and solve problems. And they need an explicit appreciation of how new knowledge can function as problem solving tools.

1.3 SOME ISSUES INVOLVING EVALUATION

According to the IDEAL Framework discussed earlier, evaluation is an important component of educational practice. When designing a Thinking

Skills program, for example, one identifies and defines a problem to be solved (e.g. "poor thinking") and explores possible strategies. One then acts on these strategies by actually implementing a program. However, if we stop here and do not look carefully at the results, we may fail to identify problems with our original ways of thinking. Through the careful evaluation of programs, ideas have a chance to evolve.

Our emphasis in this paper has been on the issue of helping students learn to think with important concepts and procedures rather than to merely think about them when explicitly prompted to do so. The emphasis suggests some constraints on the problem of evaluating thinking skills programs.

_____________ Table 1 here _______________

Table 1 illustrates a matrix for thinking about a thinking skills program. It compares the "actual success" of a program with its measured success. We can never know the actual success of a program since it is not observable. What we can observe is the measured success, whether the measure is simple observation, reports from students and parents, or formal test scores. Ideally, the measured success of a program provides an accurate reflection of its actual success. This is illustrated by the diagonal cells in Table 1 (A1, B2, C3, D4). Thus, if a program actually does a poor job of developing thinking skills we want our measurements to show this (cell A1), and if the actual success is great we want the measurements to reflect this (cell D4).

Potential dangers of receiving misleading information are reflected in the upper right and lower left corners of Table 1 (i.e. in cells A3,A4,B4 and C1, D1,D2). In these cases the measured success of our programs is at odds with their actual success.

Instances that fall in the top right corner reflect the fact that the measurements look good despite the fact that the program is actually poor.

Instances that fall in the bottom left reflect cases where the program is good despite the fact that the measurements suggest a lack of success. We briefly consider these two categories of error in more detail.

Measures that look poor despite successful programs

There are a number of reasons why successful programs can look poor given formal evaluations. The most basic one is that the evaluation tests fail to reflect what was learned. One reason may be that different students make gains in different areas. For example, some may apply their newly-aquired thinking skills to the problem of learning to comprehend what they read, others to learning about mathematics, others to organizing their time and so forth. If students develop along different paths, tests that assess change on only a few dimensions will often fail to show any gains.

A second important reason why tests may fail to reveal gains is that they generally measure individual rather than group efforts. Some of the most powerful approaches to problem solving involve the skills necessary to work cooperatively with others. If tests fail to assess changes in such abilities, we may erroneously conclude that a program is not good.

Measures that look successful despite poor programs

At first glance it may be difficult to imagine programs that look successful but really are not. On second glance, however, it becomes easy to see how such situations could arise. For example, imagine a thinking skills program that is composed of a number of components such as bridging to everyday examples of principles, instruction to students about how to

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work as a group and evaluate their own contributions to the discussion, etc. The program might also include some drill and practice exercises on reasoning problems.

Now assume that we hire an outside evaluator to assess the program. The evaluator creates a paper and pencil test of reasoning that is administered to experimental and contol groups. The experimental group performs only slightly (not statistically significantly) better than the experimental group, so a decision is made to revise the program. In the revised program much more time is devoted to paper and pencil reasoning exercises, hence there is less time for improving class discussions, identifying and analyzing instances of everyday reasoning, and so forth.

Given these revisions, the experimental students will probably perform much better than controls on the evaluation tests. Nevertheless, the actual value of the program for students may well have declined rather than been improved. A major reason for this claim is that the ability to solve specific types of formal reasoning problems may remain "inert" (to use Whitehead's term) and have little influence on activities outside the test taking situation. We believe that it is extremely important to focus explicitly on the goal of improving everyday thinking and problem solving rather than merely increasing students' scores on tests.

In summary, the goal of providing students with tools that they spontaneously think with rather than only think about when explicitly prompted is clearly a challenge. We believe that improvements in thinking and problem solving represent life-long processes, hence it is especially important that students spontaneously use various tools so that these can be evaluated and refined. An emphasis on problem identification seems to be one way to help students learn to use and refine their knowledge. It helps them learn to find important problems, and by doing so, it provides a framework for understanding the value or significance of concepts and principles. In our work, we are therefore placing increased emphasis on the design of learning environments that encourage students to identify problems on their own.

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Figure 1
Some perceptual patterns.

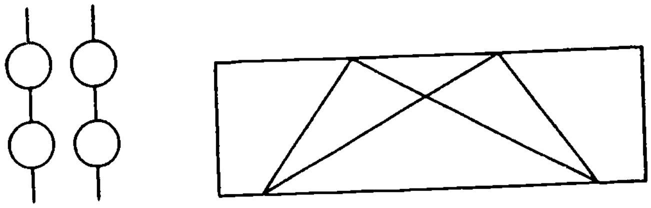

Table 1

		POOR 1	OK 2	GOOD 3	GREAT 4
POOR	A				
OK	B				
GOOD	C				
GREAT	D				

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