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ABSTRACT

It is becoming increasingly important to teach students higher-order thinking skills in addition to mere factual knowledge. Recent scientific and technological advances offer significant opportunities to implement more effective teaching of these skills. By investigating intellectual processes, cognitive science has led to a significantly better understanding of the underlying human thought processes responsible for good performance in complex domains. This paper describes briefly some of the opportunities made possible by these recent developments. Some important higher-order cognitive skills are identified and the evidence that these can be taught is discussed. It is pointed out that some current educational practices are ineffective or even harmful. Requirements needed for the effective teaching of higher-order cognitive skills are described and practical suggestions are made for promoting such teaching. Two pages of references conclude the document. (JD)

TEACHING HIGHER-ORDER THINKING SKILLS FOR A TECHNOLOGICAL WORLD: NEEDS AND OPPORTUNITIES

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Needs for General Thinking Skills

We live in a scientific and technological world based on knowledge which is increasingly large, complex, and rapidly changing. Not only is there a veritable "knowledge explosion". Much of this knowledge is also increasingly sophisticated, abstract, and highly symbolic. Furthermore, knowledge is growing so rapidly that many persons run the risk of becoming professionally obsolescent unless they continually keep learning and updating themselves.

Today's students must be prepared to cope with this kind of world if they are to function effectively in their future jobs and social roles. Providing an education that can accomplish such a preparation is, however, a difficult and challenging task. A few decades ago, many students could be satisfactorily prepared by learning a substantial amount of factual knowledge which could stand them in good stead for many years to come. But, in the face of knowledge that is rapidly growing in size and complexity, such educational approaches are becoming more and more inadequate. The sheer amount of knowledge to be learned threatens to become overwhelming. Furthermore, factual knowledge alone is of very little value without reasoning and learning skills needed to use such knowledge flexibly in diverse situations.

It is not too difficult to specify the broad outlines of an educational approach better suited to prepare students for life in our complex society. Such an approach would aim to identify and teach a relatively small number of carefully selected concepts and principles of wide applicability. Large amounts of factual information could thereby be embedded in an economical and coherent knowledge structure which students could use widely and flexibly -- _if_ they were also taught important higher-order thinking skills (e.g., reasoning processes for making inferences, methods of problem-solving, and skills of independent learning).

During the last few decades, such changes in educational approach have occurred in some rapidly changing fields (such as electrical engineering). There an emphasis on teaching predominantly factual information has gradually shifted to teaching general principles and methods. But the needs to cope with the demands of our complex society are coming to be felt much more widely by people in all walks of life. Hence it is becoming increasingly important that all levels of our educational system aim to prepare students more effectively for their future lives, i.e., that they teach higher-order thinking skills in addition to mere factual knowledge.

It is not easy to realize this goal, laudable as it may be. Higher-order thinking skills are much more sophisticated and complex than memory skills or routine applications of factual knowledge. Efforts to teach higher-order thinking skills effectively are, therefore, difficult to implement. Thus it is scarcely surprising that such general thinking skills are currently taught poorly or not at all -- with the result that many students' thinking skills remain fairly rudimentary.

Timely Opportunities for Meeting Needs

There exist promising prospects of transcending these educational inadequacies. Indeed, recent scientific and technological advances offer significant opportunities to implement more effective teaching of higher-order thinking skills.

In particular, recent years have witnessed significant progress in "cognitive science", an emerging interdisciplinary field encompassing the psychology of human information processing, linguistics, and "artificial intelligence" (the study of computers designed to exhibit human-like intelligence). By investigating intellectual processes systematically in considerable detail, cognitive science has led to a significantly better theoretical understanding of the underlying human thought processes responsible for good performance in complex domains. Very recently, cognitive science is also beginning to yield some insights about the learning and teaching of such thought processes. Although many of these insights are still fragmentary, some are ready for practical applications (Resnick, 1983).

Recent years have also seen dramatic progress in computers and other information technologies. These technologies are becoming increasingly more powerful, cheaper, and more readily available in homes, offices, and schools. If used in conjunction with the insights provided by cognitive science, such information technologies provide promising means facilitating the teaching of higher-order thinking skills. They also make such teaching potentially more widely accessible to larger numbers of students (Lesgold & Reif, 1983).

The following pages describe briefly some of the opportunities made possible by these recent developments. They first mention some significant insights revealed by recent work in cognitive science. Then they identify some important higher-order cognitive skills, indicate evidence that these can be taught, and point out that some current educational practices are ineffective or even harmful. Finally, they indicate some requirements needed for the effective teaching of higher-order cognitive skills and make some practical suggestions to promote such teaching.

Recent Insights Useful for Teaching Thinking Skills

Cognitive-science studies, carried out during the last several years, have revealed that the underlying human thought processes, needed to perform intellectual tasks, are often much more complex and subtle than had been suspected. Hence such thought processes, and especially higher-order thinking skills, must be analyzed explicitly in appreciable detail if they are to be adequately understood and effectively taught.

The following general conclusions, emerging from recent cognitive-science studies, deserve particular mention:

Tacitness of expert knowledge. The underlying knowledge, responsible for the good performance of human experts, is often largely "tacit", i.e., outside the range of their conscious awareness. (For example, most expert native speakers of a language are unable to articulate the rules specifying the correct grammatical constructions and sentence formations of their language. Much of experts' knowledge in other domains is often similarly tacit.) Correspondingly, experts or teachers are usually not consciously aware of many important thinking skills which they commonly use and take for granted. Such important thinking skills remain thus often implicit and are never explicitly taught to students.

Knowledge of novice students. Numerous studies, carried out during the last several years, have sh[illegible]at the knowledge acquired by students is often much more superficial and inadequate than presupposed by their teachers or revealed by conventional examinations. For example, more probing assessment tasks have revealed that many students, even after getting good grades in science courses, exhibit gross misconceptions about basic scientific concepts and principles. Furthermore, they often cannot use reliably or flexibly the nominal knowledge acquired by them. (See, for example, Clement, 1982; McCloskey, Caramazza, & Green, 1980; McDermott, 1984).

The difficulties go beyond mere failures of adequate learning. Students do not come to instruction with blank minds to be filled, but with preexisting conceptions about the world -- conceptions acquired as a result of prior experience, informal cultural transmission in everyday life, and previous formal schooling. These prior conceptions are often naive and inadequate. But they are extremely resistant to change and may constitute great obstacles to learning. To make instruction effective, it is thus necessary to recognize explicitly the existence of such prior student conceptions and to take deliberate steps to transcend them.

Students' preexisting conceptions about human thinking and learning tend to be even more naive and inadequate than their prescientific conceptions about the physical world. Attempts to teach effective higher-order thinking skills must thus be aware of students' prior notions about human knowledge and thinking -- and must explicitly aim to supplant such notions with more adequate conceptions and thinking practices.

Need for explicit teaching. Most conventional teaching is fairly implicit. It relies predominantly on presenting information, giving examples, and providing opportunities for practice -- assuming that students will somehow learn from these experiences. But cognitive-science research has revealed that many of the underlying thinking skills (of the kind required in mathematics, science, or writing English prose) are quite complex, depending on the subtle interaction of many essential components. Such complex thinking skills are learned rather ineffectively or inefficiently by such implicit teaching methods. (Indeed, in simpler domains, such as athletics, very explicit teaching methods are commonly used to achieve good performance.) The effective teaching of higher-order thinking skills is thus likely to require explicit and systematic teaching methods based on careful design.

Important Higher-order Thinking Skills

Recent studies of cognitive processes have helped to identify some higher-order thinking skills important in many domains. They also suggest that such skills could be taught more explicitly, with substantial benefits to many students. The following are specific examples of some higher-order thinking skills particularly important in the learning of science and mathematics, as well as widely useful outside these domains.

Problem Solving

If limited amounts of knowledge are to be used flexibly in diverse situations, one must be able to use this knowledge to make inferences and to solve various kinds of problems. Hence it is important to teach explicitly some of the important general reasoning processes needed for effective problem solving (Tuma & Reif, 1980.)

Methods facilitating search for solutions

The fundamental difficulty posed by any complex problem is the need for judicious decision making. The reason is that, although very many alternative paths toward a solution are conceivable, most of them are dead ends leading to nowhere. Proceeding haphazardly by sheer intuition or random guessing, as many inexperienced students tend to do, is thus very unlikely to lead to a solution. Instead, more systematic decision methods are needed to select promising paths toward a solution. Such general decision methods can be taught. They do not guarantee to solve all problems; but they can significantly enhance the chances of finding problem solutions without "getting stuck". The following are a few such widely useful methods facilitating the search for solutions.

Problem decomposition with explicit decisions. To solve any complex problem, it is useful to decompose the solution into successive steps of manageable size. After each such step, it is helpful to specify carefully the current state of the problem, the major obstacles hindering attainment of the solution, and some available options for overcoming these obstacles. Merely explicating this information can often suggest a useful next step toward the problem solution. All these are very primitive problem-solving methods, routinely used by good problem solvers to proceed systematically in goal-directed fashion. But they are often not taught explicitly and differ substantially from the haphazard approaches commonly used by many students.

Methods of progressive refinement. The solution of a problem consists ultimately of successive detailed steps of an argument leading from known information to some desired goal. Accordingly, the most obvious method for finding the solution of a problem simply aims to generate successively these detailed steps of the argument. Indeed, this is the method pursued by most novice students. However, this is ordinarily a very poor way of finding a solution, for the following reason: By constantly focusing attention on all the details, one tends to to get lost among a multitude of trees without seeing the forest as a whole -- and becomes thus unable to make the judicious decisions needed to find a path through the jungle.

A much more efficient problem-solving method proceeds by first outlining the solution at a gross level of description, then gradually filling in more details, and thus continuing by successive approximations until all steps have been specified in complete detail. This "method of progressive refinements" has the following advantage: The most important decisions can be made first, unencumbered by distracting and cumbersome details, and facilitate later well-informed decisions about additional details.

This method of progressive refinements is widely useful in very many domains. For example, in the domain of art, a picture is painted most effectively by first making a rough sketch of the whole scene, then filling in more lines, then adding colors, etc. (This is a much better approach than trying to paint immediately all details, square inch by square inch.) In writing English, a complex essay or report is best written by first making a rough outline of section headings, then generating a more detailed outline, and finally writing detailed prose. (This is usually a much better approach than simply starting to write successive sentences without any prior outlining.) In computer science, a computer program is best written by first making a rough flow chart, and then gradualy elaborating this into progressively more detailed instructions. (This is much a much better method than immediately trying to write successive lines of code, a practice often pursued by novice students.) In mathematics or physics, a problem is usually solved most effectively by first sketching its solution in qualitative or pictorial language, gradually refining this solution, and thus ultimately generating a precise mathematical solution. (This is usually a far better approach than that pursued by novice students who commonly try to solve problems by merely manipulating mathematical formulas.) (Reif, 1981, 1984.)

Such methods of progressive refinement deserve to be explicitly taught since they are so widely useful in many diverse domains -- and since most novice students do not use them or learn them spontaneously.

Heuristics. Heuristics are explicit general rules providing advice about how to explore possible paths toward a problem solution. (An example of such a heuristic rule is the following: If you do not know how to solve a problem, try to construct a simplified one having similar features. The solution of this simplified problem may then yield suggestions about how to tackle the original problem.) Such heuristic rules are often fairly simple and widely applicable. They can also be explicitly taught. Although they do not guarantee success in problem solving, they can provide students with valuable hints preventing them from getting irremediably stuck. (Polya, 1973; Schoenfeld, 1979, 1980, in press; Wickelgren, 1974.)

Methods for describing problems

Before a problem can be solved, it must be adequately described. Indeed, the initial way of describing a problem can often crucially determine whether the problem will be easy or difficult to solve, or whether it can be solved at all. Yet, most novice students tend to leap before they look, i.e., they immediately try to solve a problem without substantial prior effort to describe the problem with care. The consequences are sometimes fatal.

It is possible to teach some generally useful methods for describing problems initially so that they become much easier to solve. For example, there are systematic ways to summarize clearly the known and desired information in a problem, to introduce useful symbols, and to represent relevant information in pictorial form (as well as in verbal or mathematical language). There are also useful methods for redescribing problems in terms of special concepts provided by knowledge about the pertinent domain of interest (e.g., to describe problems in mechanics in terms of special concepts such as "velocity", "acceleration", and "force"). Such deliberate problem redescriptions can often greatly facilitate the subsequent search for solutions (Heller & Reif, 1984).

Methods for checking solutions

Many novice students not only leap into problems without looking first; they also do not look at their solutions afterwards. Indeed, they seem to believe that it is inefficient to waste one's time contemplating a solution once it has been obtained. This belief is ill-founded. Quite often a problem solution is incorrect or not as good as it might be. Furthermore, by examining the results obtained and the methods used, one may gain valuable insights useful for solving future problems.

There exist some simple and widely applicable methods for systematically checking problem solutions. Such methods can be fairly easily taught and can be very helpful to students who apply them routinely to all problems. Such methods involve checking whether a solution is unambiguously interpretable; whether it is complete; whether it is internally consistent; whether it is externally consistent with other available information (e.g., whether the solution is consistent with that obtained in simple special cases); and whether it is as simple as possible. (Reif & Heller, 1982; Reif, 1984.)

Ineffective or deleterious teaching practices

Current teaching practices are often not only poorly designed to teach generally useful problem-solving skills; they are sometimes even deleterious.

For example, attempts to teach problem solving often focus excessive attention on problem solutions rather than on the process of problem solving. Thus students are often given prototypical sample solutions with the hope that they will learn from them. Although some such learning occurs, it is often quite limited. The difficulty is that a solution, which is a product, reveals rather little about the process whereby the solution was produced (i.e., about all the decisions made during the process, the ways used to avoid false starts and dead ends, etc.). An understanding of effective solution processes is clearly of central importance to any student actually faced with a problem which he or she must solve independently. Yet these strategic solution processes are rarely taught explicitly.

As another example, instruction in the mathematical or physical sciences often stresses precision and mathematical formalism, sometimes to to the extent that vague qualitative language is discouraged or viewed as scientifically illegitimate. Such an emphasis is deleterious and can lead to a sterile preoccupation with mathematical formulas devoid of any insight. As pointed out previously, qualitative vague language can be very useful in mathematics or science, particularly in the beginning stages of problem solving or for discovering new results. Hence such qualitative descriptions should be deliberately taught and encouraged -- together with the ability to translate such descriptions into more precise language when this is useful.

Organizing Knowledge

The ability to use knowledge effectively depends not only on the content of this knowledge, but also on its organization. For example, a large file cabinet full of valuable information is almost useless if the file folders are randomly arranged -- because the information is then extremely difficult to find or use. Similarly, the knowledge stored in a person's head is only useful if it is effectively organized. For only then can it be easily remembered, appropriately retrieved for problem-solving tasks, and readily modified or generalized.

Many novice students do not appreciate the importance of organizing their knowledge effectively, nor are they able to organize it effectively even if they try. Hence it is not surprising that students' knowledge is often quite incoherent -- consisting of miscellaneous facts only loosely connected to each other. Such fragmented knowledge is easily forgotten, difficult to use flexibly, and a poor basis for further learning -- particularly in complex domains, such as science or mathematics.

Thus it is important to organize carefully the knowledge taught to students -- and to teach them general skills for organizing their own knowledge effectively. There are indications that such skills can, in fact, be taught. For example, certain forms of knowledge organization are particularly useful for facilitating the flexible use of knowledge (Eylon & Reif, 1984). Good methods have been devised for teaching skills of summarizing knowledge acquired by reading -- so that this knowledge can be better understood and used to make various inferences (Palincsar & Brown, 1984). Skills of organizing scientific knowledge have also been taught to students so as to make them better able to describe experiments and to carry them out flexibly in a laboratory (Reif & St. John, 1979).

Current teaching practices are not well designed to teach students effective skills of organizing their knowledge. Usually, predominant attention is focused on the <u>content</u> of the knowledge conveyed to students, rather than on the <u>organization</u> of this knowledge. Furthermore, the knowledge presented to students is often organized in forms that do not facilitate effective remembering and use; even worse, students are thereby presented with poor models of how to organize their own knowledge.

<u>Interpreting Concepts</u>

The concepts acquired by students are often vague and diffuse - with the result that they are frequently misinterpreted or misapplied. The difficulties are particularly severe in scientific or mathematical subjects where concepts need to be defined clearly and unambiguously. The difficulties are aggravated by the fact that newly learned concepts must often be carefully distinguished from superficially similar concepts used in daily life. Correspondingly, it is found that many students, even after lengthy and seemingly successful instruction, cannot appropriately apply the concepts learned by them -- and often have gross misconceptions. Such difficulties may even extend to very basic concepts. (For example, many college students cannot define, or appropriately apply, the concept of "area" which they have presumably learned in elementary school and encountered repeatedly since that time.)

It seems possible to identify and teach some higher-order learning skills to facilitate a more effective acquisition of new concepts. Such learning skills involve, first and foremost, the realization that a concept involves not only a mere definition, but a collection of ancillary knowledge needed to make the concept flexibly usable. Such ancillary knowledge includes explicit procedures for interpreting the concept, knowledge of certain standard properties, familiarity with important special cases, and knowledge of the conditions when the concept may legitimately be applied (Reif, in press). Such ancillary knowledge is often not explicitly taught. However, there are good indications that it could be taught and that students could thereby become better independent self-learners (Reif, Larkin, & Brackett,1976).

Improved Conceptions about Thinking and Learning

Many students have primitive or misleading conceptions about human thinking and learning. Such conceptions can greatly impede students' learning since they profoundly influence what students deem important, how they study, and how they assess their own performance (Schoenfeld, 1983). Hence it is necessary to modify students' naive beliefs by teaching them more realistic conceptions about effective human thinking and learning.

For example, many students believe that understanding some topic involves primarily a knowledge of relevant facts to be remembered or applied in standard situations. Correspondingly, their primary attention is devoted to memorizing factual knowledge and displaying it on tests. However, this is a very limited and sterile conception of knowledge and understanding; for instance, it is almost useless for learning to solve problems. By contrast, a more sophisticated conception of understanding emphasizes the ability to use knowlege flexibly in diverse situations -- to solve problems, to explain, and to make various inferences. Such a conception focuses a student's attention not just on factual knowlege, but on the thought processes whereby such knowledge can be used and extended.

A student's learning goals and criteria for "understanding" become then totally different.

As another example, many students look upon their mistakes as sources of embarrassment -- or as accidental happenings to be rectified and dismissed as rapidly as possible. By contrast, cognitive science leads to the following more sophisticated perspective: (1) Mistakes are not freak occurrences, but are expected to occur whenever humans perform complex tasks. Hence one must deliberately devise methods for preventing mistakes, for detecting them if they are committed, for diagnosing them appropriately, and for correcting them. (2) Mistakes reveal very useful insights about intellectual functioning (in the same way as diseases provide extremely useful insights about normal physiological functioning). Hence mistakes should be exploited as valuable sources of information about one's own thought processes and their possible improvement.

Such a changed point of view about mistakes entails different and more productive ways of learning. Instead of being casually dismissed, mistakes become then worthy of study in their own right and valuable sources of enlightenment. However, most current teaching practices do <u>not</u> encourage this point of view. Indeed, they often do the very opposite, creating environments where students are predominantly embarrassed or penalized because of their mistakes.

<u>Requirements for Teaching Higher-order Thinking Skills</u>

The preceding paragraphs have tried to identify a few higher-order thinking skills widely important in many different domains. Appreciable educational benefits would ensue if such skills were explicitly taught (some even at rather early stages of children's education). Furthermore, there are indications that some of these skills could be taught effectively.

Successful teaching of such higher-order thinking skills is, however, far from simple and demands attention to the following requirements:

Careful educational design. Higher-order cognitive skills are complex and thus difficult to teach; furthermore, they must often be taught consistently over appreciable periods of time. Haphazard, sporadic, or poorly informed teaching activities are thus unlikely to be effective. Instead, success depends crucially on carefully designed teaching activities, partially based on recent insights from cognitive science.

Teaching in context. The teaching of higher-order thinking skills cannot be accomplished in some single special course. Instead, higher-order thinking skills must be taught explicitly -- and then consistently illustrated and applied in various courses dealing with different subject domains. Only in this way can students acquire new habits of thinking and practice these extensively in a variety of contexts.

Changed assessment criteria and methods. Higher-order cognitive skills aim to endow students with problem-solving and learning skills transcending the mere acquisition of factual knowledge. Yet many current tests assess predominantly such factual knowledge. It is clearly difficult, if not impossible, to teach important intellectual skills if these are not recognized by assessment instruments designed to evaluate the performance of students or of schools. Hence it is important to design new and more sophisticated assessment methods that do specifically assess higher-order cognitive skills.

Changed time allocations. One cannot teach higher-order thinking skills without deliberately allocating time for doing so. Such time may need to be gained by omitting the teaching of some less important factual knowledge. Indeed, judicious selectivity about what to teach or to deemphasize would be intrinsically useful for upgrading curricula and making them better suited to educate students for a changing society. Furthermore, if students have been taught improved thinking and learning skills, they should ultimately be better prepared than if they merely possessed more extensive factual information. In fact, they should then be better able to use their knowledge flexibly and better able to learn new knowledge rapidly whenever needed.

Modified teacher perceptions and training. It would be difficult or impossible to teach students higher-order thinking skills if the teachers themselves do not appreciate the importance of such skills or have unduly primitive conceptions about human thinking or learning. Successful efforts to teach higher-order thinking skills would thus require some changes in teacher education and efforts to reorient the perceptions of practicing classroom teachers.

Changes in textbooks. If higher-order thinking skills are to be taught, textbooks would have to place a greater emphasis on the teaching of such skills. Instead of being predominantly concerned with teaching factual knowledge, they would need to teach some widely useful methods of problem solving and ways of organizing knowledge -- and would need to apply these to specific knowledge domains.

Exploitation of new information technologies. Computers and other new information technologies can potentially provide powerful means for helping to teach higher-order thinking skills. If software is well-designed, computers can engage students very actively in their own learning, can provide extensive opportunities for practicing general thinking skills, and can supply students with feedback well adapted to their individual needs and rates of learning. Furthermore, the use of such information technologies could help to overcome some of the bottlenecks caused by limitations of teacher time and expertise (Lesgold & Reif, 1983.)

What Can be Done Now?

The task of successfully teaching higher-order thinking skills is far from easy. Furthermore, our basic understanding of complex thought processes is still limited and fragmentary. Nevertheless, this understanding is sufficient to suggest directions which can fruitfully be explored at present and progressively improved in the future. The following are some specific actions which could usefully be undertaken at the present time:

* Promote greater awareness of the need to teach higher-order thinking skills and of the existing opportunities for doing so.
* Attempt to reduce the prevalence of current teaching practices which encourage inefficient or deleterious thinking habits.
* Make efforts to enlist good talent to modify textbooks, and produce educational computer software, in ways that promote the teaching of higher-order thinking skills.

* Establish some research and development projects aiming to generate good prototype instructional efforts and materials for teaching higher-order skills. (Such prototypes could greatly enhance knowledge about the effective teaching of such thinking skills. They would also be very effective in encouraging more widespread teaching of such skills.)

Actions of this kind would be good beginning steps toward the teaching of generally important higher-order thinking skills, would help to improve education in many domains, and would prepare students significantly better for life in our complex technological society.

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