Seven Thinking Skills Essential for Learning

Nicholas C. Wilson
Introduction

Thinking skills seems to be a pervasively hard to define topic. Indeed, certain aspects of human thought excite different regions of the brain, and some types of thinking affect only how people perceive information, not how they use information. The purpose of this paper is to examine seven thinking skills, general and specific, which seem to have a great deal of influence over how people learn, both academically and in the real world. These thinking skills vary from conscious reasoning and rational thought, to subconscious brain activity such as organization of information. From the perspective of formal education, it is important not only to make these types of thinking explicit to thinkers and learners, it is important to convey how these skills can be adopted, improved, and utilized. By making one's thinking conscious and explicit, one can use whatever new information is learned, and appropriately refine the skills necessary to understand language, solve problems, and retain knowledge better.

I. Chunking

An important skill that research has shown to separate novices from experts in various domains is the ability to “chunk” knowledge. It is this ability to organize meaningful information according to a certain function or strategy that defines expert ability. As stated by John Bransford of the National Research Council (2000), “Since there are limits on the amount of information that people can hold in short-term memory, short-term memory is enhanced when people are able to chunk information into familiar patterns (Miller, 1956).” Indeed, experts in chess, for instance, are able to “see” potential moves based on the board configuration (Chase and Simon, 1973; Anderson, 2005). Because their knowledge of board configurations and series of moves are chunked accordingly, experts act more quickly
and efficiently than novice chess players. Novices, however, lack the necessary organizational structure of knowledge that experts possess, and therefore have to analyze the configuration and the implications of each potential move (Anderson, 2005). Chase and Simon (1973) posited that chess masters effectively have board configurations and move strategies stored in memory. In a study on expertise, they asked chess masters to reproduce board configurations after glancing at a test chessboard. The results indicated that experts reproduced configurations after each glance based on meaningful chunks of game relations, such as pawn chains. Newell and Simon (1972) found, as well, that chess masters possess production rules for certain chunks of information. That is, depending on the configuration of the pieces, a chess expert will know what sort of strategy to employ (e.g., offensive or defensive).

Experts’ ability to chunk meaningful patterns of information has been demonstrated in various other domains, as well (NRC, 2000). Experts in electronics, physics, mathematics, and teaching, have shown that mastery in a domain enhances this capacity. Hinsley et al (1977) and Robinson and Hayes (1978) found that mathematicians quickly recognized patterns of information for problems involving certain principles and requiring specific analyses. Glaser and Chi (1988) submit that experts can recognize complex patterns where novices cannot because they have developed, over time, conceptual schemas for types of problem representations.

Mastery of pattern recognition, or chunking, comes most obviously from practice in a certain domain. A common approach in science and engineering courses is to have students practice (repeatedly) solving certain types of problems that involve important principles. Typically, solving the assigned problems will require the using the same specific technique or sequence of steps. Anderson calls this process “tactical learning’ (2005, p. 289).
The benefit of tactical learning is that it provides students the learning experiences necessary for developing the ability to recognize meaningful patterns of information (NRC, 2000). Research suggests that through repeated tactical learning opportunities, mastery of knowledge chunking and development of expertise can be enhanced (Simon, 1980; Bransford et al, 1989).

II. Hierarchical Analysis

A key component of expertise in a domain is the ability to organize one’s knowledge structurally. By analyzing a given problem, one might find that it encompasses many levels of theoretical principles or has underlying assumptions. Bransford (NRC, 2000) refers to the ability to recognize and organize elements of information according to a set of ordered principles as “hierarchical analysis.” Experts exhibit facets of this skill in their approach to problem solving. Indeed, one demonstrated difference between experts and novices in physics is that experts group problems by their underlying physical principles, whereas novices tend to group problems merely by the equations used to solve for certain physical elements in the problems (Chi et al, 1981).

Hierarchical analysis requires the problem solver to dissect a problem into its constituent parts, determine which parts are necessary for analysis of the problem, and choose the processes necessary to reach the solution. Automobile mechanics need to understand how each mechanical part of a car works on a stand-alone level, as well as how it interacts with the other parts of the car’s machinery. Based on the sometimes incomplete or abstract information given by the car owner (e.g., “It goes ‘kah-chunk’ every time I start the car in cold weather.”), a mechanic needs to be able to determine the affected system (i.e., exhaust, heating, braking, etc.), the individual parts that require examination or replacement,
and finally, how to fix the problem. However, in order to do this, one needs to learn the individual components of each system in the car, what each system does, how the parts come together and function as a system, and how to repair common problems. With developing expertise, advanced mechanics become familiar with typical issues of various makes and models by year, such as the Tappit Brothers on National Public Radio’s “Car Talk” program. These two radio hosts offer a great example of the hierarchical analysis necessary to diagnose and solve atypical car problems. Because they have a wealth of knowledge and experience in the field, the two can determine which part of a car is causing an issue and how to approach remedying it, based only on the year and model of the car, and a brief description of the problem.

Dufresne et al (1996) used computer programs to teach undergraduates in an introductory physics course this approach to problem solving. Using the program, students were required to “perform a conceptual analysis of the problems based on a hierarchy of principles and procedures that could be applied to solve them (Dufresne, from NRC p. 171).” Results of the study showed that students who used the hierarchical analysis approach to problems performed significantly better than students who were taught by the standard curriculum. As well, the results demonstrated that by learning the steps of hierarchical analysis, the experimental group categorized problems more accurately according to their fundamental principles.

Leonard et al (1996) used a similar approach to instruct engineering students in problem solving. Before tackling the problem, students were required to perform a qualitative analysis of the strategies necessary for finding a solution based on three components: the major principle involved in the problem, a defense of why that principle applied to the problem, and the procedural steps required for applying the principle. The
students taught under these guidelines were able to categorize problems according to their underlying principles much better than those taught in a typical course.

These studies and others like them (Eylon and Reif, 1984; Heller and Reif, 1984) imply that organizing one’s knowledge is a critical process of problem solving, and that hierarchical analysis is a necessary skill for the development of expertise in a domain. By constraining a student’s problem solving approach to the requisite steps of conducting a hierarchical analysis, students can learn to master this method of structuring knowledge (Defresne et al, 1996; Leonard et al, 1996).

III. Reflection and Monitoring

The ability to monitor one’s own level of understanding of a subject is an essential characteristic of what is known as “adaptive expertise” (Hatano and Inagaki, 1996). By being recognizant of gaps in knowledge, or being metacognizant, one can flexibly adapt an approach to a subject to eradicate those knowledge gaps, and ultimately gain a better understanding of the subject. Indeed, research has shown that experts share this metacognitive approach when dealing with new ideas (NRC, 2000), and more importantly, that children can learn this skill to increase transfer (Palinscar and Brown, 1984) and improve understanding in physics (White and Frederiksen, 1998), written composition (Scardamalia et al., 1984), and mathematics (Schoenfeld, 1983, 1985, and 1991).

Metacognition as a skill is particularly important to master in that it entails real, deep, understanding – a characteristic of thinking that most likely everyone can agree is valuable for any type of work or education, and in everyday life. For example, teachers employ metacognitive skills when engaging students in learning exercises. In fact, effective teaching often requires one to reflect on one’s own knowledge of a subject, as well as on how
effective and meaningful instruction and learning tasks are executed. This approach has been adopted and tested by a group of researchers who use teachable agents in educational software as a means to promote self-reflection in learning a task. Biswas, Schwartz, Leelawong, Vye, and TAG-V (2005) developed a teachable agent program called “Betty’s Brain” to combine the strategies of learning by teaching and self-regulation to instruct students on river ecosystems. Their study indicated that students who learned self-regulation tactics performed better than non-regulation students on far transfer questions and were better prepared to learn new concepts.

Additionally, metacognitive approaches to education have been validated through the use of inquiry and reflection (White and Fredericksen, 1998). Using the ThinkerTools Inquiry Curriculum, White and Fredericksen (1998) found that low-level 7th-9th grade students could outperform high school physics students taught under a non-inquiry approach on problems that required transferring principles of Newtonian mechanics to real-world scenarios.

For obvious reasons, metacognition as a practice cannot be taught explicitly in the way that facts or mechanical procedures are. Self-reflection, by its nature, is introspective and often takes place in the form of an inner monologue. Hence, reflection and metacognition present challenges for formal instruction. Reminders, feedback, and frequent, informal assessments, thus, may be the best ways of engaging students in metacognitive behavior. Through rehearsal of these techniques under the tutelage of a mentor, students can strengthen their metacognitive skills enough to gain the confidence necessary to employ them in unsupervised or nonacademic conditions. Evidence from research supports that computerized teachable agents are an effective means for developing these skills (Biswas et al., 2005). When presented in a constructivist environment in which students maintain
primary control, teachable agents and mentors can provide feedback and opportunities for reflection at the learner’s chosen pace. As with the Betty’s Brain software, agents will only provide feedback when prompted, but can still suggest ways to promote better learning and teaching.

The skills students learn from this type of instruction not only promotes transferability between concepts, but develops in a person the ability to learn deeply about a topic, even beyond the scope of academia.

**IV. Logical Reasoning**

Logical Reasoning is a skill employed during differing stages of problem-solving. Typically, research has shown that humans are rather deficient in reasoning skills (Anderson, 2005), but this delegation seems only appropriate in the face of mathematics and formal logic, such as the logical reasoning that computers use. Learning to reason logically is a necessary instrument of interpreting information, making inferences, and determining action in human’s lives. Indeed, some research has shown human have innate tendencies to reason correctly for certain conditions, like scenarios involving permission (Cheng and Holyoak, 1985). Therefore, improving human reasoning for abstract situations may require consideration of how humans reason naturally under certain circumstances.

One example of humans’ failure to employ logical reasoning to abstract situations is the Wason Selection Task (Wason and Johnson-Laird, 1972). In an experiment, participants were presented with four cards:

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   E   K  4  7
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The researchers then asked the subjects to verify the logical condition, “if a card has a vowel on the one side, then it has an even number on the other side.” Ninety percent of participants turned over the “E” card – a logically informative task in the sense that an odd number would disprove the statement. However, only 25% turned over the “7” card – the only other logically informative choice in that a consonant on the other side could also disprove the statement. Choosing the “7” card represents the modus tollens step of this selection task, and may explain why so few participants selected it.

Yet, in a similar study, Griggs and Cox (1982) found that participants overwhelmingly selected appropriate logical verifiers when the selection task mirrored a real-world situation. Griggs and Cox presented the subjects with the task of validating the legality of people drinking at a hypothetical college party. The partygoers’ ages (above or below 21) and beverages (beer or Coke) were displayed on cards in the same fashion as the Wason task above:

<table>
<thead>
<tr>
<th>Drinking beer</th>
<th>Drinking Coke</th>
<th>16 years old</th>
<th>22 years old</th>
</tr>
</thead>
</table>

Seventy-four percent of the participants correctly chose logical informants, including the modus tollens condition – a stark contrast to the 25% in the Wason experiment. Cheng and Holyoak (1985) posited that this difference in logical reasoning resulted from the familiarity of the participants in the Griggs and Cox experiment with the setting of the problem. They submitted that the participants interpreted the situation according to a “permission schema” based on experience with certain rules (e.g., no drinking under the age of 21). Indeed, Cheng and Holyoak (1985) tested and confirmed this hypothesis, indicating that peoples’ logical reasoning is superior in familiar social situations, especially those
pertaining to the violation of societal rules. Clearly, humans have the ability to reason logically, but the accuracy of these reasoning skills depends on the familiarity of the individual with the scenario.

Thus, to gain a mastery of logical reasoning, one must achieve a level of experience with various contexts that call for such reasoning. Cheng, Holyoak, Nisbett, and Oliver (1986) found that such practice enabled reasoners to develop “practical reasoning schemas,” such as the permission schema described above. According to their research, training for reasoning in these practical reasoning schemas greatly improves one’s ability to reason correctly across contexts, despite a lack of research showing that formal study in logical reasoning increases any such transfer.

V. Means-Ends Analysis

Means-ends analysis (Newell and Simon, 1972) is a method of approaching problem solving through the creation of subgoals. A problem solver uses these subgoals as a means of closing the gap between the current state and the final goal state. As an approach to problem solving, means-ends analysis is similar to that of difference reduction, in that both methods are an attempt at eliminating the biggest differences in the problem states. Yet, means-ends analysis allows the problem solver to reverse directions when facing blocked operators, and to set the subgoal of removing such a roadblock. Hence, “the means temporarily becomes the end” (Anderson 2005, p. 260).

This approach can be illustrated by the “Missionaries and Cannibals” problem. In the problem, three missionaries and three cannibals are on a riverbank. The problem is to get everyone across the river using a boat that can carry only two people at a time. The only rule is that the cannibals can never outnumber the missionaries. A difference-reduction
strategy would have the problem solver attempting to make the current state of the problem more like that of the goal state (everyone on the other bank), but it becomes evident through this process that at a specific point, one can no longer reduce the difference between the current state and goal state without “back-tracking,” or seemingly increasing the difference between the two states. It is at this juncture that the problem solver must create the subgoal of eliminating the specific blocked operator and adopt the means-ends analysis approach.

The “Tower of Hanoi Problem” (Anderson, 2005) is another example that requires such a strategy. In the problem, three disks of differing sizes (A = smallest, B = middle, and C=largest) can be moved amongst three pegs (1, 2, and 3). In the start state, all three disks are stacked on the first peg with the largest disk on the bottom and the smallest disk on top. The goal of the problem is to transfer all three disks to the third peg, stacked again according to size. The rules of the game are that only the top disk on a peg can be moved, and that a disk can never be placed on a smaller disk. Anderson (2005) traced out the 45 different steps of difference reduction and means-ends analysis required to solve this problem. He describes one instance of means-ends analysis employed as follows:

“One difference between the goals and the current state is that disk C is not on peg 3... A subgoal set up to eliminate this difference... tries to find an operator to reduce the difference. The operator chosen is to move C to peg 3. The condition for applying a move operator is that nothing be on the disk. Since A and B are on C, there is a difference between the condition of the operator and the current state. Therefore, a new subgoal is created to reduce one of the differences – B on C” (p.263-264).

Indeed, this problem requires many such subgoals be set and attended to before the final goal state can be reached.

Naturally, setting up and achieving so many subgoals increases the amount of time one must spend on a problem (Anderson, Kushmerick, and Liebere, 1993; Ruiz, 1987). Yet, in a study using the Tower of Hanoi problem, Kotovsky, Hayes, and Simon (1985) found
that after initially struggling with difference reduction, test subjects quickly solved the problem by switching to a means-ends strategy.

The main obstacle a problem solver is faced when employing means-ends analysis is knowing what subgoals to set. In other words, a problem solver must know what operators to use for the given problem state. Thus, a problem solver must have a sizeable arsenal of operators with which to approach various problems. Humans have demonstrated the ability to learn operators passively and actively, by instruction and experience. The latter method implies that mastery of problem solving requires that one learn by “trial by fire” – a suitable means under the right circumstances (i.e., physically safe, contextually appropriate, etc.), but somewhat unrealistic in many others (e.g., learning surgery). More appropriately, one can learn by being explicitly told how to solve a problem, or by seeing someone else do it. Reed and Bolstad (1991) found that, depending on the problem, people learned better by one of these two approaches, but that generally, “best learning occurs when participants have access to both methods” (Anderson 2005, p. 250). Thus, for the purposes of mastering goal-setting and means-ends analysis, one should ideally learn through the use of examples and direct instruction.

VI. Identifying Language

Language is parsed according to numerous rules that fall under the basic umbrella of grammar. Rules regarding constituent structure, language syntax, and semantics all determine how people interpret a string of words and give it meaning. Researchers have compiled an overwhelming amount of evidence to show how comprehenders integrate semantic and syntactical structure when making sense of ambiguous statements. Yet, it is in
how these structures are processed within the brain that presents the source for much
conflict in the fields of linguistics and psychology (Anderson, 2005).

Fundamentally, in order to comprehend a given sentence, the individual constituents,
or phrases, of the sentence must have meaning. Indeed, humans can learn from an early age
how to interpret certain patterns of words (constituent units) – a behavior that enables
humans to extract meaning from long, complex sentences. Graf and Torrey (1966)
conducted a study to demonstrate that being able to identify the constituent structure affects
how easily people interpret a sentence. They presented a sentence in two forms: one in
which the words were displayed inline with their constituent boundaries, and the other in
which constituent boundaries were ignored, like this:

<table>
<thead>
<tr>
<th>Form A</th>
<th>Form B</th>
</tr>
</thead>
<tbody>
<tr>
<td>During World War II</td>
<td>During World War</td>
</tr>
<tr>
<td>even fantastic schemes</td>
<td>II even fantastic</td>
</tr>
<tr>
<td>received consideration</td>
<td>schemes received</td>
</tr>
<tr>
<td>if they gave promise of shortening the conflict.</td>
<td>consideration if they gave promise of shortening the conflict.</td>
</tr>
</tbody>
</table>

Participants in the study better understood the passage when presented in form A. Hence,
being able to identify the constituent structure has implications for how well one interprets,
or parses a sentence.

Comprehenders also use syntactic and semantic cues when interpreting a sentence.
Word order, inflection, and semantic structure (even for syntactically incorrect phrases) play
an important role in how humans make sense of sentences, as Bates, McNew, MacWhinney,
Devesocvi, and Smith (1982) demonstrated in a study on ambiguity. In the study,
participants attempted to interpret an ambiguous string of words, such as:

Chased the dog the eraser.

Or,
Chased the eraser the dog.

American English-speakers had difficulty agreeing on how to interpret the first phrase. They either followed rules of syntax (implying that the eraser chased the dog), or semantics (suggesting that the dog chased the eraser – a much more plausible conclusion). However, there was little disagreement on how to interpret the second phrase – the dog chased the eraser.

Although these examples serve to illustrate how parsing is critical for language comprehension, the question of mastering sentence interpretation remains. Yet, the findings of the above studies suggest that because humans have natural tendencies for interpreting constituent structure, minimizing confusing or ambiguous elements of written text would enhance language comprehension. From a formal education standpoint, this implies that textbooks, classroom reading material, and written assignments should be structured in alignment with cultural language norms. For instance, because American English-speakers rely more on syntactical cues (Bates, McNew, MacWhinney, Devesocvi, and Smith, 1982), educational materials should avoid using sentences that might mislead readers into interpreting ambiguous statements semantically, where syntactical interpretations are intended (e.g., “Chased the eraser the dog”).

As such, parsing of written text may best be mastered by dissecting sentences into constituent subparts. Rules of syntax and grammar are taught this way, and can provide learners with the opportunity to hone their skills at identifying sentence constituents. Being able to identify sentence constituents can lead to better language comprehension, and may allow for better semantic interpretation of ambiguous statements.
VII. Inference in Language

Much to the lament of many high school students struggling with their first exposure to Shakespeare, understanding language is not merely a function of parsing a written passage into its constituents and making sense of the word order. Full language comprehension often requires the comprehender to make inferences, connections, and conclusions in the absence of direct, declarative statements (and sometimes in their presence). Yet, inferencing - or “utilization” (Anderson, 2005) – is not required only of those who aspire to deconstruct Shakespearian literature. It is a skill required even in the most mundane of personal conversations, in addition to when reading text.

Singer (1994) illustrated how people make inferences from a text. He used the following examples to demonstrate this:

1. Direct statement: The dentist pulled the tooth painlessly. The patient liked the method.
2. Backward inference: The tooth was pulled painlessly. The dentist used a new method.

After reading these statements, Singer asked test subject to validate that the statement, “A dentist pulled the tooth.” Although explicitly stated in the first passage, the subjects had to infer the connection between the pulled tooth and the dentist in the second condition. Singer argued that this was an example of a backward inference – an inference made by connecting previous information to the current condition.

Long, Golding, and Graesser (1992; from Anderson) illustrated another form of inference in a study in which participants read a story containing the sentence, “A dragon kidnapped the three daughters.” When asking about the story, the researchers found that participants made “forward inferences” that the dragon’s goal was to eat the daughters, although no such suggestion was made in the story. Specifically, forwarding inferences
connect information to possible future conditions. The results, the researchers argued, demonstrated that readers use inferencing to understand characters’ goals in a story.

The implications of such studies indicate that much of the meaning we derive from written text is a product of our ability to make backward and forward inferences. Or in other words, that we can use limited information to connect a current situation to the past, or to predict possible outcomes in the future. This skill has far-reaching consequences for not just academic pursuits, but for everyday life, as well. People often need to make valued decisions based on partial or inadequate information. Doctors may have to use the patient’s medical history to infer the patient’s diagnosis. More dramatically, consider the situation in which a person sees smoke coming from a known flammables storage facility. The person might infer that flammable material had caught fire and presented a greater danger than a mere chimney fire. For obvious reasons, being able to make inferences is a very important skill to develop.

Personal experience might indicate that people are apt to make different inferences based on how a given set of information is presented. The way one constructs a sentence or inflects certain words in a sentence can have some bearing on how another makes judgements about a certain situation (this seems to happen quite frequently with teenage children (personal experience)). Indeed, research has shown that even the articles chosen to introduce a noun in a sentence can affect how a reader interprets the statement’s meaning. Loftus and Zanni (1975) presented test subjects with a film of an automobile accident and then asked them a series of questions, including, “Did you see a broken headlight?” to one test group, and, “Did you see the broken headlight?” to the other. Despite the absence of it in the film, the group that was asked the latter question was more likely to affirm seeing a broken headlight. Because the form of the question implies the presence of a broken
headlight, participants inferred that it had indeed appeared in the film. Anderson relates this result to having serious implications for eyewitness testimony, but it can have other social and academic implications, as well. Translations of speeches or text may affect how the speaker or author is received, for instance. Hence, learning to differentiate between the inferences that people make based on information is a key component of effective communication. By considering the ways in which oral or written communication is affected by the inferences people make, one’s skills for language comprehension can progress. Practice in the form of reading text, or answering ambiguous questions that force one to make inferences can serve as a means of mastering this skill. Indeed, children are often asked to make inferences from reading materials in classrooms. Thus, gaining a familiarity with situations in which one is forced to infer information (linguistically or experientially) seems to be the best way of learning inferencing skills.

**Conclusions**

Because the range of human thought and learning is so diverse, it is important from the perspective of formal education to make thinking explicit and flexible. The skills discussed above are meant to illustrate how the ability of the brain to recognize, organize, and use information in myriad ways to achieve a greater understanding of phenomena, to solve problems, to communicate, or just to strengthen one’s memory. Formal education should make a priority of exploring these different skills and adapting educational approaches to capitalize on the tremendous ability of the human brain for diverse thinking. Making these skills explicit to learners, and showing how these skills can enhance one’s ability for higher-level thought, should be a part of everyday curricula, for it seems that many woes plaguing humanity are caused by our inability to use knowledge, not our capacity for it.
Bibliography


