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How Can One Specify and Teach Thinking Skills?

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By conceptualizing thinking as a form of behavior, the methods of learning theory become applicable to the teaching of thinking skills. Most thinking skills can then be defined and specified as heuristics that are useful in diverse situations. The many situations and problems, social and other, that a student encounters throughout the day, can be described in terms of the heuristics that would help the student to make the many required small decisions. Such heuristics generally take the form of identifying these situations, as, for instance, "I'm uncomfortable," "I'm faced with a problem," "I'm trying to understand something," and for each such type of situation, to invoke a set of applicable questions like, "Have I seen a similar problem?" "Is the problem worth solving?" "Do I need help?" Each of these heuristics would have follow-on heuristics, thus forming trees that branch. Learning theory provides effective procedures for teaching such decision trees. Once learned and applied repeatedly, heuristics become automatized and increasingly covert until they have turned into habitual thinking patterns. A practical approach to teaching a wide range of thinking skills, including creativity, is to treat thinking skills as heuristics that are learned in overt form and then made covert and automatized by dint of extensive repetition.

Key words: thinking skills, critical thinking, inquiry skills, creativity, heuristics, problem solving, equivalence relations, education, concept learning

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Most modern educators agree that students must acquire useful thinking skills. Whether they are called critical thinking, analytical thinking, inquiry skills, or creativity, the challenge is to define what they are with enough specificity to enable us to create conditions in which they will be learned, and to know when they have been.

What are these thinking skills? For children, the most useful ones are those that can be used throughout the day, in situations that the child normally encounters. Whether we call them social skills, self-management skills, or other, part of the educator's challenge is to identify, define, and teach them, and weave them into the fabric of students' day-long functioning—to influence the many small decisions students must make in the diverse situations they encounter. It is not enough to teach thinking skills that can be summoned and performed only on cue.

This paper describes a way to accomplish this for a wide range of thinking skills. The approach is based not merely on asking students thought-provoking questions, giving them problems to solve, or pointing out mistakes in their thinking. It is based on specifying the desired behavior in a form in which students can then acquire it.

Thinking as Behavior

The approach conceptualizes thinking as a form of behavior—behavior that we can't observe while it is occurring. The only difference between thinking and other behavior is the degree to which the body's effectors (mainly muscles) are engaged—often not at all (Hefferline & Keenan, 1963; Jacobson, 1932; Keller & Schoenfeld, 1950; Mechner, 1994, pp. 10-16; Skinner, 1957, p. 432). When a chess player is pondering his next

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move, he is engaged in behavior we can't see. This invisible behavior culminates in the player's decision to make a certain move, which may then be executed by the hand or the voice. Neurobiologists have shown that every overt act, whether complex or simple, is preceded by neural activity lasting anywhere from split seconds to much longer. Some of the extensive literature on this topic is reviewed in Mechner, 1994, (pp. 6-7).

Why is it useful to conceptualize thinking as behavior? Because doing so places at our disposal the substantial tool kit of techniques for modifying behavior, and thus enables us to apply those tools to the teaching of thinking.

Converting Overt Into Covert Behavior

If the behavior is invisible, how can we modify it or teach it? An important method is first to establish it in overt form—the form in which it is observable and accessible for modification. Having modified it to our satisfaction, we can cause it to become increasingly covert and finally invisible, at which point we call it thinking (Mechner, 1994, pp.10-16).

It becomes invisible as a result of extensive practice and repetition. A familiar instance of this process is the child's transition from reading out loud to sub-vocal reading to silent reading, which takes most children a year or two. For most people, this same transition also occurs for the facts of arithmetic and for many motor skills that become automatic and lightning fast after the overt verbalization components have fallen away.

The teacher can shape the overt verbalization through the use of feedback, differential reinforcement, coaching, or modeling. It can then become covert and automatized through practice and repetition, with the articulation of words progressively diminishing. At the end of this process the behavior persists, but in a form in which it may be completely disengaged from the muscles.

Admittedly, in all of these examples, the invisible form of the behavior—the thinking version—may be quite different from its previous overt version, in content as well as in form. When we instruct a person to "Think out loud" (Silman, 1999), or ask, "What were you thinking when you did that?" the words we get in response may have little correspondence to the thought processes to which we were referring. But a teacher need not be concerned about the degree of correspondence between the overt and covert forms of the behavior. What matters is the observable and practical *effect* of the covert version. In reading, it's comprehension; in arithmetic, it's the answer; in chess, it's the move that gets made. Once the behavior has become covert and automatized, we care mainly about its effects.

Heuristics[1]

So, what is the behavior that one can teach in overt form that will turn into useful thinking skills when it has become covert? Heuristics. A heuristic is behavior (e.g., a question, probe, or prompt) that points to a useful next step. Familiar examples are "rules of thumb," "educated guesses," and "probes." Heuristics often take the form of questions that are answered with sets of choices—alternatives for what to do or ask next. There is a substantial scientific literature on the use of heuristics in human affairs (Kahneman & Tversky, 1973; Kahneman, Slovic, & Tversky, 1982; Polya, 1945; Tversky & Kahneman, 1974). Modeling and simulation are widely used heuristics in science and technology (Frigg & Hartmann, 2006). Familiar examples of heuristics are statistical sampling, trying something out, tasting a food, or questions asked in the parlor game "20 questions."

How are heuristics different from algorithms? We normally apply the term "algorithm" to instructions or procedures that specify a series of steps that yield clear-cut or specific answers, as in the procedures for doing long

[1]From the Greek *heuriskein*, to find.

division or for checking out a particular piece of equipment (Mechner, 1963, 1967, 1981). The term heuristic, on the other hand, is applied to actions that may not lead to specific answers but that suggest promising ways to move ahead. An approximation algorithm, for instance, functions as a heuristic. Heuristics are like fuzzy algorithms: to the degree that one is unable to specify precisely what kind of answer an algorithm will provide, we would lean toward calling it a heuristic.

Much of our daily behavior can be viewed as involving heuristics. Familiar examples are checking up on things, looking around, making lists, and browsing. We do not normally articulate our heuristics explicitly—they are usually more like fleeting thoughts, un-verbalized judgments, and automatic behavior patterns of which we may be unaware. They help us make the many small decisions required by the steady stream of unstructured situations we encounter in our daily lives (Kahneman, 2011), as well as many large decisions, including life-changing and ethical ones (e.g., Prentice, 2004).

Decision Trees

Both algorithms and heuristics can be formulated as decision trees. In that form, learning theory provides educators with effective methodologies for teaching them (Landa, 1965; Mechner, 1963, 1967, 1981). These methodologies will be discussed in more detail below.

One of the most common every-day instances of a heuristic that initiates a decision tree is the question, "What is the situation I am facing?" We may not articulate it in this particular way, or at all, but we constantly act accordingly. Below are some of the common answers—the follow-on heuristics.

- **I'm in a conflict situation.**
- **I'm physically uncomfortable.**
- **I'm trying to resist a temptation.**
- **I feel a strong emotion—anger, fear, jealousy, loneliness.**
- **There is something I am obligated to do because of an agreement I made**
- **There is something I should do because someone needs me to do it.**
- **I want a certain person to do some thing.**
- **I want to get something.**
- **I want to fix something.**
- **I want to prevent something from happening.**
- **I'm in danger/trouble.**
- **I'm faced with a problem.**
- **I want to understand something.**
- **I want to find out something.**

These are obviously not the only situations a student may face in the course of a day, but they are common ones. Each of them, once identified, sets the occasion for summoning some further heuristics. For example:

- **I'm physically uncomfortable.**
  - Thirsty?
  - Hungry?
  - Cold?
  - Tired or sleepy?
  - Need to go to the bathroom?
  - Something hurts?
- **I feel a strong emotion.**
  - What is the emotion I am feeling? (anger, fear, jealousy, loneliness?)
  - Am I in danger of acting in a way I may regret?
  - Might my emotional state be preventing me from seeing what is real?
  - Do I want to try to change how I feel?
- **I'm faced with a problem.**
  - I will try to state the problem.
  - What might the solution look like?
  - Do I know how to solve it?
  - Should I try to solve it?
  - What can happen if I don't?
- **I want to try to solve it.**
  - Have I seen a similar problem?
  - Can I simplify or reframe the problem?
  - Should I use trial and error?
  - Should I try parsing or diagramming the problem?
  - Should I try to approximate or estimate the answer?

• Should I try to find an algorithm that might work?

Many of the above-listed heuristics are evidently applicable to the development of the thinking skills involved in social interactions, and each one of them has possible follow-on heuristics, For example:

- **I'm in a conflict situation.**
  - What is my goal?
  - What are reasons for the other party's actions?
  - What is the other party thinking/feeling?
  - What actions are available to me?
  - What is the worst outcome I can imagine?

Students learn to apply these types of heuristics to the diverse social situations that occur throughout the day. At Queens Paideia School[2] a learning manager, upon witnessing a minor altercation, might propose considering why the other party did what they did, how they might have felt, and how else the student might have handled the situation. After many experiences of this type, students learn to internalize these heuristics and make them part of their repertoire for use in similar situations.

As each of the heuristics in the above examples branches into follow-on heuristics, the result is decision trees with branches and leaves. Most adults make these decisions and judgments at a fleeting, covert level, without articulating them explicitly. We make them so fluently and automatically that we forget we once had to learn them, perhaps in our childhoods.

It must be understood that the above branching heuristics are just arbitrarily chosen illustrations. There are innumerable kinds of such trees and branches—as many as there are people with their special and idiosyncratic ways of navigating their world. Some heuristics and their follow-on heuristics are clearly more effective than others, and we all have our preferences. Behaving appropriately in all of these various types of situations, and being fluent in making those fleeting judgments is what defines a mature and competent adult.

As educators, we call many of these trees of heuristics "social skills," "self-management skills," or "learning skills." We make choices as to the particular trees we help our students learn. The choices we make inevitably reflect our own particular world-view and experience, and hopefully our wisdom.

Teaching Decision Trees

By formulating decision trees as chains of multiple discriminations, learning theory offers effective strategies for learning heuristics. The reason this way of conceptualizing thinking skills is useful is that there is a substantial body of knowledge on how to teach multiple discriminations efficiently (e.g., Mechner, 1963, 1967, 1981). These are the general steps:

Step 1: Limit the number of branches for each decision point to the 3 to 6 range. In cases where there are more than 6, it is usually more efficient to subdivide the branch into smaller branches

Step 2: Every follow-on heuristic, down to the "leaves," is a concept, in the sense of a set of discriminations between classes and generalizations within classes (Keller & Schoenfeld, 1950). Learning a concept means learning to generalize among diverse instances of the class and to discriminate between that class and other classes (Hull, 1920, 1943; Mechner, 1961, 1963, 1967, 1981).

Step 3: In teaching sequences of acts (learning theory generally conceptualizes sequences as chains—chains of responses, of multiple discriminations, or of concepts), is it usually most efficient to start at the end (Gilbert, 1996; Keller & Schoenfeld, 1950; Mechner, 1961, 1963, 1981, 1994; Millenson, 1967; Verhave, 1966). Consider the first of the above follow-on heuristics, "I'm uncomfortable." That heuristic is a more abstract concept than those that fol-

[2]Queens Paideia School is a small New York independent school that uses the Paideia Individualized Education model in which every student progresses along a customized learning plan that consists of behaviorally defined learning objectives.

low from it, like "I'm hungry" or "I'm tired." Children always learn to identify ways of being physically uncomfortable long before the general concept of "uncomfortable." They can understand and learn this more abstract concept only after they have learned several of its instances. The same principle applies to each of the other follow-on heuristics. Each concept's instances and non-instances should be learned before moving up the tree to the next set of branches, in the direction of increasing abstractness. The last heuristic to be learned should be the first one, namely, "What is the situation I am facing?" In short, the most efficient strategy is to teach the leaves before the branches and the branches before the stem.

Step 4: Get the learner to apply each concept overtly as many times as necessary for it to become an automatized thinking skill—covert, fleeting, and invisible—with the understanding that this process may take years (Mechner, 1994, pp 10-16).

Thinking Skills Learned at Queens Paideia School

The database of learning objectives used at Queens Paideia School includes a variety of thinking skills—different ones for different ages and achievement levels. A particular heuristic that drives much of the school's social studies curriculum is one that students learn to apply to historical events, historical figures, discoveries, inventions, wars, cultural practices, beliefs, and current events. They learn to invoke this heuristic when faced with one of these historic events or topics, often in the context of writing a report on it. The heuristic consists of the following set of questions:

- When did it happen?
- Where did it happen?
- Who was involved?
- Why is it believed to have happened, what is the evidence?
- What has been the effect?

The immediate learning objective is for students to ask and apply these same questions routinely in diverse situations they may encounter and in which this heuristic is applicable. The longer-term strategy is to establish the heuristic in overt form by having students apply those same questions repeatedly, over a period of time, to approximately 150 suggested topics or events. The goal is for those questions to become part of the student's standard repertoire of thinking skills. Once learned, it doesn't matter whether we call it "critical thinking," "analytical thinking," or "inquiry skill."

Self-Observation and Reflection

Reflection is a set of thinking skills that can act as potentiators of both academic and non-academic progress, and of many other aspects of personal development and functioning (Fredrick, 2009). The term reflection generally refers to self-observation that is retrospective—that examines past behavior and experiences, and what can be learned from them.

At Queens Paideia School, students engage in reflection daily after academic work sessions. Common reflection heuristics are:

- What were my goals/learning objectives?
- Which ones did I achieve?
- What did I learn?
- How difficult was it?
- What obstacles did I encounter?
- What might I do differently in the future?

The follow-on heuristics for each of these often suggest lessons that can be drawn from the way it went. The objective, again, is for these follow-on heuristics to become, over time, part of the student's habitual reflection process. Students are also encouraged to keep a journal in which they record and describe their actions and thoughts. In general, recalling and reviewing past events and experiences is a heuristic that improves students' ability to observe their own behavior, think about it, and learn from it.

These are some additional thinking skills for which useful heuristics can be learned:

- **Thinking ahead.** Heuristics can include considering possible chains of consequences, as in chess and other types of interactions. Useful heuristics are, "How will the other person respond if I do this?" "How might I then respond?" and "Should I think some more before acting?" (Mechner, 1994, Endnote 3)
- **Conceptual thinking and concept building.** Useful heuristics are, "What are some examples?" "To what is this similar or analogous?" "How can the concept be stated abstractly?"

Creativity and Imagination

What is it? Can it be learned? Efforts to define creativity or imagination often focus on the result achieved, like its newness or originality (e.g., Mumford, 2003) or the traits and attributes of unusually creative or imaginative individuals, often with reference to the concept of "genius" (Eysenck, 1995; Weisberg, 1993).

It may be more useful to address the subject with questions like, "What are the behavioral phenomena to which people apply these terms?" (Marr, 2003). This type of question may be a useful heuristic for devising approaches to defining and teaching the various behaviors that may be involved.

Here is an example: In the past 50 years, a great deal has been learned about concept formation, specifically about equivalence relations and their significance (Arntzen & Hansen, 2011; Fields & Watanabe-Rose, 2008; Sidman, 1994; Verhave, 1966). It may be useful to think of our behavior repertoire, including all of our knowledge, as being made up of millions of concepts. These are all potentially linked to one another indirectly via transitive equivalence relations that span multiple nodes (the term node is used here in the equivalence theory sense [Fields & Watanabe-Rose, 2008; Fields & Moss, 2001; Moss-Lourenco & Fields, 2011]), or via the innumerable complex relations based on hierarchies, logic, classifications, similarity, empirical experience, causality, aesthetics, physical properties, etc. The node concept offers a behavioral account of how all the millions of concepts in a repertoire are potentially linked to one another, even if the linkages are long nodal chains.

When potential transitive links that span many nodes become actual links, we often call the result "conceptual leaps," "leaps of imagination," or "creativity." Often, neither the author of the connection nor the observer can trace or describe the leap's path through the multi-dimensional node space (for instance, "It just came to me," "Eureka!" or "I had an epiphany."). The larger the number of nodes separating two concepts, the more creative or imaginative the leap may seem (Koestler, 1964).

Can Creativity and Imagination be Learned?

How might this analysis help us *teach* creativity or imagination? By devising heuristics that promote the occurrence of multi-nodal leaps. We could then teach these heuristics to students and provide them with practice in using them.

Some such heuristics are, "What does this remind me of?" "Where else can I apply this idea?" "Should I try something that seems really outlandish?" These, along with many others, can be learned and practiced until they have become part of the student's normal thinking repertoire, at which point they could be called creativity or imagination (Nickerson, 1999). A widely used heuristic used by writers, artists, composers, and scientists is, "Put it aside for a while and come back to it later," sometimes referred to as incubation (Smith, 1995). The reason this works may be explained as follows: Focusing on a task or problem intensely for an extended time often narrows and restricts the range of concepts being considered and brought to bear. To gain perspective and "think outside the box," metaphorically speaking, it often helps to step away from the box. "Putting it aside" creates distance, and distance increases the amount of terrain that comes into view. As the visible panorama of the concept space expands, potentially productive nodal leaps can be identified more easily.

Learning to Make Distant Connections

At Queens Paideia School, the learning managers frequently use the heuristic of asking students to identify relationships not only in the academic realm but also in their daily experiences and between things they already know. Applying to historic events the heuristic, "What else was happening in the world at that time?" prompts the student to seek connections among disparate domains like science, technology, the arts, politics, cultures, wars, or religions—domains that ordinarily tend to be considered separately. Another heuristic directed at making connections is the question, "How did the (historic) event affect how we live today?" prompting connections across time periods, disciplines, and thematic modalities. By applying these and other heuristics repeatedly to dozens of topics, students make them part of their habitual thinking repertoire. Looking for connections by using such heuristics is a skill that improves with practice.

A basic and widely used stratagem for facilitating nodal leaps can be described as "class expansion," or "class enrichment,"—increasing the size and membership of individual conceptual classes. This often involves increasing the number and range of instances that define concepts, as when learning that the class "animals" includes not just familiar mammals, birds, and fish, but also microscopic creatures and humans. That is, of course, what occurs in education. The larger the individual conceptual classes, the greater the likelihood that adjacent ones will overlap, thereby facilitating the making of connections between them (Fields & Reeves, 2001).

One of the most common heuristics teachers suggest when a student is struggling is, "Think about it." Thinking about something often involves traversing a particular multi-nodal transitive path through the concept space a number of times, with the result that it becomes less transitive or multi-nodal each time it is traversed, due to learning. Every time a connection is made, it becomes more firmly established. The learning process short-circuits paths that start out as multi-nodal transitive linkages and turns them into one-stop direct connections. This could be one of the important ways we learn and become more creative by "thinking" about a particular matter. It is said that when Sir Isaac Newton was asked how he came up with the laws of motion, he replied, "By thinking about it constantly."

However effective such techniques may be, there is no getting around the fact that great leaps of imagination and creative acts that appear to involve distant connections occur most often in skill domains in which the individual already has a rich and fluently available conceptual repertoire (Ericsson & Charness, 1994). New trans-nodal relations form most easily in richly populated concept spaces where there are multiple potential pathways for large multi-nodal transitive leaps, especially when the conceptual classes are already large and a great deal of short-circuiting can occur. So, to become creative in chess, first become a grandmaster with fluent access to a huge number of chess positions and stratagems; to become a creative composer of music, develop a huge and readily available repertoire of harmonic progressions, melodies, and rhythms; ditto for becoming a creative painter, writer, or scientist.

A Heuristic for the Educator

It may be evident that the approach to conceptualizing, defining, and teaching thinking skills described in this paper is itself a heuristic, this one for use by the educator in teaching thinking skills. Every thinking skill can be defined in terms of the set of situations in which a heuristic or tree of heuristics is applicable. Having defined these situations and trees, the educator first teaches the leaves and branches of the tree in overt form, as concepts, using standard concept formation procedures. The sequence in which the concepts are taught starts with the leaves and ends with the stem. Students repeat and practice the chains of heuristics in situation after situation with the goal of making them so fluent and automatic that they are invoked every time an applicable situation is encountered.

In summary, by conceptualizing thinking as behavior—behavior that does not engage the body's effectors—we can apply the methods and techniques of learning theory. By then formulating thinking skills as sets of heuristics that are applicable to certain situations or challenges, and conceptualizing these heuristics as behavior that takes the form of questions and decision trees, a wide range of thinking skills becomes definable and teachable.

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