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How to improve thinking

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Introduction

How can we improve our thinking? The answer in principle is straightforward. What we need is to have an unlimited working memory for holding information in mind while we think about it, to know everything, to think at the speed of light about all the possibilities consistent with what we know and about all the counterexamples inconsistent with it. With these accomplishments, we would be able to solve hitherto intractable problems. We would avoid errors that we would otherwise make – some of which have catastrophic consequences. We would outthink other people. We might believe that their mental powers are defective; and they would despise us for our uncanny ability. If we all had these superhuman abilities then we would live longer – intelligent individuals do, and we might be wiser and live in a better world than we do now.

But, do our mistakes in thinking – yours and mine – really matter? Skeptics may say, no. We cope with life. We survive; and we tend to notice our errors and to recover from them. Mistakes in thought, they say, matter more to researchers in psychological laboratories than to society as a whole. Their claim, however, is itself a mistake. The Darwin awards remind us of the consequences of egregious errors. As their founder Wendy Northcutt remarked, such errant individuals “improved the gene pool by eliminating themselves from the human race in an astonishingly stupid way.” Like the man who kissed his pet, they fail to think of a possibility. (His pet was a rattlesnake.)

Many disasters hinge on the same failure. Consider just one example: the fate of the car ferry The Herald of Free Enterprise, which sailed from the Belgian port of Zebrugge on March 6, 1987. It was a “roll on roll off” ferry in which the cars had driven down a ramp through the doors in the bow. The sailor who was then supposed to close the doors was asleep in his bunk. Another sailor saw that the doors had been left open, but did nothing about it. Those on the bridge asked for no report on the bow doors. So, the ship put out to sea with its bow doors wide open. Once it had left the harbor, the sea poured in, the vessel capsized, and 188 people drowned. What allowed such a blunder to occur was a mistake in thinking. The company had a policy of “negative reporting” in which the crew reported only untoward events. No-one made a negative report about the doors, and so disaster was almost inevitable. The correct policy is to demand positive reports too. The failure to confirm that the bow doors had been closed
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would then have alerted the master of the vessel to the problem. The policy of negative reports is attributable itself to a failure to think of a possibility. The possibility in which, for whatever reason, an appropriate negative report is never made.

Granted the need to improve thinking, is it possible? On this question, reasonable grounds exist for skepticism. No strong signs show that thinkers have improved in ability over the course of history. Artists now are no better thinkers than their ancient peers. Scientists know much more than, say, Aristotle did, but not because they are smarter. Their disciplines lead to knowledge. Teachers take pleasure in the blossoming of their students’ talents, and acknowledge that experience can improve thinking. But they know that individuals nevertheless differ in ability, especially in their creativity. Hence, skeptics conclude that even if there are methods for teaching thinking, there are limits on what they can achieve.

In fact, methods are advertised to improve thinking. Like diets, they are numerous, hard to follow, and often ineffective. Some are grand schemes such as the project in the 1980s to increase the intelligence of the population of Venezuela. It worked insofar as test scores were concerned, but its long-term effects are uncertain (see Nickerson, 1985). Other methods are as miniscule as the one to be described below. But, as with a diet, no good reason exists to adopt a method of improving thinking unless it can be shown to work. The efficacy of a diet is easy to assess: those who use it, either lose weight or not. But, the efficacy of tools for thinking is more problematic. Suppose someone devises a method for improving creativity (e.g., de Bono, 1970; Kaufman et al., this volume), how are we to assess it? Psychologists may say: use a standard “before and after” design: measure a sample of individuals’ creativity, assign half of them at random to the regimen for improving creativity and half of them to a control regimen, and then re-assess the creativity of the two groups (see Burden, this volume). The authors of a meta-analysis of studies of training in creativity concluded that such regimens work (Scott, Leritz, & Mumford, 2004). But the studies rely on valid assessments of creativity, and their validity is itself uncertain (cf. Long & Plucker, this volume). What counts as creative is subjective and dependent on historical context. A more objective domain is the focus of this chapter, the teaching of reasoning.

Formal logic and reasoning

If you want to improve your reasoning, a seemingly plausible way to proceed is to learn logic. It could be the key to good reasoning, though an understanding of how, in fact, we reason might be more useful than an understanding of how we ought to reason. As a test case, consider the reasoning of John Snow in his researches in the mid-nineteenth century on how cholera spread from one person to another (see, e.g., Johnson-Laird, 2006, Ch. 27). His research led to a new discipline – epidemiology. He corroborated his theory in ingenious ways, but it was vindicated only after his death. When he started his research, doctors reasoned as follows:

If cholera is transmitted within a household then it is communicated either by inhalation of noxious particles or their ingestion.

If cholera is transmitted over long distances then it is from inhalation of a miasmal contagion in the air or from some other unknown mechanism of communication.

So, the doctors concluded, cholera is communicated from one person to another in various ways. From his work as an anesthetist, Snow was familiar with the laws governing the diffusion of particles in a gas: their quantity in a given space diminishes inversely with the square of its
distance from the source of the particles. He was therefore able to reject the miasmal hypothesis, and so he concluded:

Cholera is transmitted by the ingestion of physical particles.

Readers might ask themselves whether or not this conclusion follows validly from the assumptions above, that is, must Snow’s conclusion be true if these premises are true?

Logic can help us here. Its calculi contain formal rules of inference, such as a rule equivalent to:

If A then B.
A.
Therefore, B.

where the values of the variables A and B can be any propositions whatsoever. The first step in using logic is to establish the logical form of the premises (see Keene, 1992), and the second step is to match these forms to corresponding formal rules that enable one to construct a chain of inferences that prove that the conclusion can be derived from the premises (see Jeffrey, 1981). The first step is to summarize Snow’s argument in order to reveal its logical form. Here is such a summary, abbreviating its constituent propositions:

1 If in-house then inhalation or ingestion.
2 If at-distance then inhalation or other-mechanism.
Therefore, ingestion.

It is clear that a proof depends on further premises. The first two missing premises are obviously that cholera is transmitted within households and over long distances:

3 In-house.
4 At-distance.

The formal rule of inference above then enables us to derive the following conclusion about the mechanisms:

Ingestion and (inhalation or other-mechanism).

That is what doctors believed, but Snow eliminated inhalation from his knowledge of the gas laws, and so he added the premise:

5 Not inhalation.

The appropriate formal rules of inference yield the conclusion:

Ingestion and other-mechanism.

Snow, however, drew a much more specific conclusion, and the reason why goes to the heart of his thinking. He presupposed a parsimonious solution, and accordingly a single mode of communication, and so the other mechanism was merely ingestion too:
Therefore, cholera is communicated by ingesting particles.

With the addition of the extra premises, the inference is valid: if its premises are true, then its conclusion is true too. But, is its conclusion true? As Aristotle taught us, we shouldn’t confuse a valid conclusion with a true conclusion. The truth of the conclusion to a valid inference depends in turn on whether its premises are true. In Snow’s case, they are. He had reached a true conclusion. Particles of the disease could be picked up from patients’ clothing or bedding, and they could be transmitted long distances in the water supply (see Johnson-Laird, 2006, Ch. 27). He had figured out the mode of transmission without any knowledge of germs, and his “particles” were later identified as the bacteria, \textit{Vibrio cholerae}.

The use of logic in this way depends on formal rules of inference, which take time and effort to master. It also depends on the analysis of logical form. No algorithm exists that can carry out this task for everyday inferences. It is extraordinarily difficult – so difficult that it is the principal objection to teaching people formal logic in order to improve their thinking. As an example of its difficulty, consider Mr. Micawber’s famous advice in Charles Dickens’s novel, \textit{David Copperfield}:

Annual income twenty pounds, annual expenditure nineteen pounds nineteen and six, result happiness. Annual income twenty pounds, annual expenditure twenty pounds ought and six, result misery.

What is its logical form? Two sentences in a discourse normally have the form of a conjunction. But, this structure is remote from the true logical form. The best way to proceed is consider the possibilities that Mr. Micawber had in mind, allowing that he says nothing about what happens when expenditure equals income – presumably happiness, too. His advice yields two possibilities, abbreviated as follows:

- Income £20 & expenditure ≤ £20 & happiness
- Income £20 & expenditure > £20 & unhappiness, i.e., misery

The simplest way to capture these two possibilities in logic is with an assertion having the logical form:

\[ I \land (E \iff H) \]

where the variable I has as its value the proposition, “Your income is £20,” E has as its value, “Your expenditure is less than or equal to £20,” and H has as its value “you are happy.”

The example establishes three points. First, the analysis of logical form is tricky indeed. Second, it can proceed by the enumeration of the possibilities to which assertions refer. Third, if human reasoning is in fact based, not on formal rules of inference, but on possibilities, then the analysis of logical form serves no purpose (Johnson-Laird, 2010).

One other difficulty in the pedagogical use of formal logic is a finding due to Patricia Cheng and her colleagues (Cheng et al., 1986). Participants took a semester’s course in logic concerning such terms as, “if,” “or,” and “and.” They were then tested with a version of a well-known reasoning problem, the “selection” task (Wason, 1966). Given the assertion based on “if”:

If there’s an A on one side of a card then there’s a 2 on the other side

the logically trained participants, unlike the control group with no such training, understood the relevance of a card bearing a 3 as a potential counterexample to this assertion. So, the training
in logic seemed to have paid off. But, the experimenters also couched the task using the general assertion:

Every card with an A on one side has a 2 on the other side.

Now, the effect of training in logic vanished, and the logically trained group no longer understood the relevance of 3 as a potential counterexample to the assertion. The reason for their failure was that the course in logic hadn’t dealt with such terms as “every.” The training had failed to transfer to a logically equivalent expression couched in other terms. The failure in transfer and the difficulty of logical analysis eliminate logic as a practical method to improve reasoning.

The ineffectiveness of logic should not be used as an argument against logic itself. Some critics, such as Lin (1939, pp. 424 et seq.), have written about the dangers of applying logic to human affairs. Much of this rhetoric, however, rests on a confusion between valid inferences and true conclusions. If there is at least one false premise, then a valid inference no longer guarantees a true conclusion. Yet, many educators who teach students to reason have also abandoned logic. One of their concerns is the difficulty of logical analysis. Another is the putative gap between logic and everyday inferences. The philosopher Stephen Toulmin (1958) argued that logic is inappropriate for the analysis of real arguments (see also Scriven, 1976). Premises have different roles in these arguments, and logic fails to distinguish them. Many pedagogues shared this skepticism, and it led to a movement for “critical thinking” and for its teaching in schools. Members of the movement advocate all sorts of teaching methods (Sternberg, Roediger, & Halpern, 2007) – the identification of fallacies (e.g., Johnson and Blair, 1994), the use of special diagrams to analyze arguments (e.g., Fisher, 1988), pragmatic analyses (e.g., Walton, 1989), and the use of computer programs to analyze inferences (e.g., Verheij, 2003). Likewise, the last twenty years has led to a growth of studies of informal reasoning (e.g., Rips, 1998; Brem & Rips, 2000; Green & McCloy, 2003). These studies have shown that human performance is poor and that reasoners often overlook alternative lines of argument. Likewise, many of the strategies that occur in laboratory studies of deductive inference re-appear in studies of informal reasoning (Kuhn, 1991, p. 274). Proponents of the various systems of critical thinking have yet to converge on a common method that results in robust improvements in reasoning. In fact, the ultimate concerns about any inference should be whether its conclusion follows validly from its premises, or, failing that, at least plausibly from them, and whether its premises are true. An alternative conception of reasoning, which takes these considerations into account, leads to a simple way to improve reasoning.

The theory of mental models

The theory of mental models – the “model theory” henceforth – postulates that human reasoners think about the different possibilities compatible with the premises and with their knowledge (Johnson-Laird, 1983). They build mental models of the resulting possibilities. This idea is not foreign to logic, because logicians in the twentieth century developed accounts of the meaning of calculi in terms of models for which they could define the concept of validity as opposed to the concept of proof (see, e.g., Jeffrey, 1981). The theory of mental models is a psychological analog of this idea. People represent possibilities in mental models, and so if a conclusion holds in all of them then they judge that it follows of necessity. If it holds in most of them then they judge that it is probable. And if it holds in at least one model then they judge that it is possible. The model theory has a long history (see, e.g., Johnson-Laird, 1983; Johnson-Laird & Byrne, 1991; Johnson-Laird, 2006), and its latest version aims to unify deductive and numerical
reasoning about probabilities (e.g., Khemlani, Lotstein, & Johnson-Laird, 2012). Perhaps the theory’s most crucial prediction for our purposes is that the more possibilities that individuals have to keep in mind in order to make a valid inference, the more difficult that inference will be – with the ever-present danger that, like the master of *The Herald of Free Enterprise*, they will overlook a possibility.

The theory has been implemented in a computer model, and it is instructive to examine its performance with the earlier inference about the transmission of cholera. Consider its abbreviated premises again:

1. If in-house then inhalation or ingestion.
2. If at-distance then inhalation or other-mechanism.
3. In-house.
4. At-distance.

The program yields five mental models of alternative possibilities from these premises:

<table>
<thead>
<tr>
<th>Ingestion</th>
<th>Inhalation</th>
<th>Other-mechanism</th>
</tr>
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<tbody>
<tr>
<td>Ingestion</td>
<td>Inhalation</td>
<td>Other-mechanism</td>
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<td>Ingestion</td>
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<td>Inhalation</td>
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<td></td>
</tr>
<tr>
<td>Inhalation</td>
<td>Other-mechanism</td>
<td></td>
</tr>
</tbody>
</table>

But, Snow’s further premise:

5. Not inhalation

reduces these possibilities to one:

<table>
<thead>
<tr>
<th>Ingestion</th>
<th>Other-mechanism</th>
</tr>
</thead>
</table>

At this point, Snow’s parsimony reduces the possibility to the single mechanism of the ingestion of particles of the disease.

If a theory of reasoning is any good, then it should have lessons for how to improve reasoning. The model theory implies that one danger in reasoning is that individuals overlook possibilities. The reader may say, but we knew this danger already. Perhaps. But, in that case, why are so many theories of reasoning based on formal rules of inference, which do not concern possibilities, and why are so many pedagogies of thinking based on procedures that do not invoke them, either? The failure to envisage a possibility is not the only source of errors, but it is a major one. The next section describes an important stepping-stone to a pedagogical method to reduce the danger.

**Reasoning and diagrams**

Over the centuries, logicians have developed various diagrammatic methods designed to improve reasoning. They have focused on “syllogisms,” which Aristotle was the first to analyze, for example:

Some pets are poodles.
All poodles are dogs.
Therefore, some pets are dogs.
Traditional diagrams of the sort that Euler used to teach logic consist of circles that can overlap to represent the relations between such sets as pets, poodles, and dogs. They have not survived stringent tests of their efficacy in the psychological laboratory (e.g., Calvillo, DeLeeuw, & Reving, 2006), but a special version of these diagrams, which reduces their number for a given syllogism, does improve reasoning (Sato, Mineshima, & Takemura, 2010; Sato & Mineshima, 2012). There are sixty-four possible pairs of syllogistic premises, and the inferences they yield vary considerably in difficulty (Khemlani & Johnson-Laird, 2012). Studies have yet to show that diagrams help with all of them, and, more importantly, that they transfer to other sorts of inference.

In pioneering studies, the late Herb Simon and his colleagues described several ways in which diagrams help to provide information more rapidly than other media, but they wrote, “the differential effects on inference appear less strong” (Larkin & Simon, 1987, p. 71). They took the view that reasoning is largely independent of representation if the sets of inference rules are equivalent for the different sorts of representation. Likewise, Barwise and Etchemendy (1994), who pioneered the use of diagrams in teaching logic, argued that diagrams can present a wealth of details that hold in conjunctions, such as: the vehicle has six wheels and a rear-mounted turret and a large front bumper. They wrote, “It is much harder to use [diagrams] to present indefinite information, negative information, or disjunctive information” (p. 80). In contrast to these skeptical views, the model theory predicts that diagrams that make it easy for individuals to envisage alternative possibilities will enhance their reasoning, even from negative assertions and from disjunctions. Experiments corroborated this claim. Inferences based on two disjunctive premises are normally quite difficult, for example:

Julia is in Atlanta or Raphael is in Tacoma, or both.
Julia is in Seattle or Paul is in Philadelphia, or both.
What, if anything, follows?

It follows validly, for instance, that Raphael is in Tacoma or Julia is in Seattle, or both. Very few people reach this or any other valid conclusion, but the chances of doing so can be increased with the use of a diagram. Not all diagrams are helpful. The key is that the diagram should help in envisaging alternative possibilities. Figure 7.1 illustrates such a diagram. The task is to complete a path from one side of the figure to the other by inserting the shapes representing people into the slots representing places. So, the diagram presents a problem equivalent to the verbal premises above: the shape standing for Julia can be in Atlanta or Seattle, or in neither; the shape standing for Raphael can be in Tacoma or not; and the shape standing for Paul can be in Philadelphia or not. Diagrams of this sort had a striking effect on reasoning with a variety of different problems (Bauer & Johnson-Laird, 1993). The twenty-four participants who reasoned from the diagrams drew 74 percent correct conclusions from them whereas the twenty-four participants who reasoned from equivalent verbal premises drew only 46 percent correct conclusions. Responses were also much faster to the diagrams (a mean of 99 seconds) than to the verbal premises (a mean of 135 seconds). With a diagram such as Figure 7.1, individuals can imagine moving the pieces into their slots. They make a simulation using a kinematic mental model in which they move the lozenge designating Julia into the slot representing Atlanta, and they know that the result represents the proposition that Julia is in Atlanta. They can describe this possibility in their conclusion. The process is faster and more accurate than one based on having to construct a mental model from verbal premises. More recent results have shown that individuals can make mental simulations using a kinematic model of a complex process (Khemlani et al., 2013). The success of such diagrams raised the question of whether individuals
could be taught to construct their own diagrams, and whether this procedure would improve their reasoning. In fact, there is a simpler solution.

**The model method**

When individuals develop strategies for reasoning, some of them spontaneously use a single diagram that represents all the possibilities compatible with the premises (Van der Henst, Yang, & Johnson-Laird, 2002). They draw these diagrams in various ways. Some people draw vertical lines down the middle of the page to separate the different possibilities. Some draw horizontal lines. Some draw circles round those items in the premises that occur in one possibility. The use of diagrams in an experiment was more flexible than other strategies, because people could extend them to new sorts of inference. Victoria Bell converted this spontaneous strategy into a pedagogical procedure, namely, the “model method” (see Bell, 1999). It consists of a single command:

*Try to construct all the possibilities consistent with the given information.*

Students are then taught how to put this command into practice. It takes them about two minutes to learn the procedure. Here’s an example:
Imagine that an unknown disease has the following characteristics:

1. Ingestion of germs transmits the disease or it has some other mechanism of transmission, or both.
2. If ingestion of germs doesn’t transmit the disease then their inhalation does.
3. Ingestion of germs transmits the disease if and only if the germs survive in gastric juices.
4. Inhalation of germs doesn’t transmit the disease.

There are three possibilities consistent with the first premise, and we represent them in three columns separated by vertical lines using sensible abbreviations:

- **Ingestion**
- **Other mechanism**
- **Ingestion**

The second premise calls for inhalation to be added to any possibility in which ingestion does not occur:

- **Ingestion**
- **Other mechanism**
- **Ingestion**
- **Inhalation**

The third premise calls for the survival of germs in gastric juices to be added to any possibility in which ingestion is a mode of transmission:

- **Ingestion**
- **Other mechanism**
- **Ingestion**
- **Inhalation**
- **Survival**

The fourth premise eliminates any possibility containing inhalation:

- **Ingestion**
- **Other mechanism**
- **Ingestion**
- **Survival**

This diagram yields a valid conclusion:

The ingestion of germs and their survival in gastric juices transmits the disease, whether or not there is some other mechanism.

A simple example of the preceding sort sufficed to explain the model method to participants. To determine its efficacy, Bell carried out several experiments. In her first study, she tested
participants in two blocks of reasoning problems in which they evaluated given conclusions. One group was taught the model method as illustrated above after the first block of trials, and the other group was left to their own devices in both blocks. The model method had a striking improvement on reasoning with a test battery of problems: the participants were right on 95 percent of the inferences, and they took a mean of 15 seconds to evaluate each inference. In contrast, the control participants were right on only 66 percent of inferences, and took a mean of 24 seconds to evaluate each inference (Bell, 1999).

A second experiment demonstrated a similar improvement when the participants were not even allowed to draw diagrams. They were taught the method as before, but then they were told merely to imagine the different possibilities. The problems were a little easier than those in the first experiment, and those who were left to their own devices were right for 80 percent of the inferences. But, those who were taught the model method were right on 93 percent of the inferences.

Consider the following problem in which the task is to evaluate a given conclusion:

1. Either ingestion of germs transmits the disease or else it has some other mechanism of transmission, but not both.
2. The disease has some other mechanism of transmission if and only if inhalation of germs also transmits it.
3. Either inhalation of germs transmits the disease or else the germs survive in gastric juices.

Does it follow that ingestion of germs transmits the disease if and only if the germs survive in gastric juices?

A strategy that some individuals spontaneously develop is to make suppositions rather than to use diagrams (Van der Henst et al., 2002). Suppose, for instance, that ingestion is the mechanism. It follows from the first premise that the disease doesn’t have some other mechanism of transmission. This intermediate conclusion implies in turn from the second premise that inhalation does not transmit it. And this conclusion implies from the third premise that the germs survive in gastric juices. The chain of intermediate inferences has therefore established that if ingestion of germs is the mechanism then the germs survive in gastric juices. But, the conclusion also asserts that ingestion is the mechanism only if the germs survive in gastric juices. To check that this proposition holds too, reasoners need to make a further supposition. One way to proceed is to suppose that the germs survive in gastric juices, and then to check the implications of this supposition. It follows from the third premise that their inhalation does not transmit the disease. This intermediate conclusion implies from the second premise that the disease does not have some other mechanism of transmission. Which, in turn, implies from the first premise that the disease is transmitted by ingestion of germs. So now the chain of inferences has shown that if the germs survive in gastric juices then their ingestion is the mechanism of transmission. The premises therefore imply:

Ingestion of germs transmits the disease if and only if the germs survive in gastric juices.

Bell (1999) carried out a third experiment to compare the model method with the method based on suppositions. Its results showed that those who were taught the model method were the more accurate (over 90 percent correct) than those who were taught the use of suppositions (around 80 percent correct), who in turn were more accurate than those who were left to
their own devices (around 65 percent correct). Finally, Bell extended her findings in a fourth experiment, which showed that the model method worked even when individuals formulated their own conclusions. Those participants who were taught the method drew many more valid conclusions (80 percent) than those who were left to their own devices (52 percent).

In sum, the model method, though it takes only a few minutes to teach, has robust effects on the accuracy and speed of reasoning. It helps reasoners to bear in mind the alternative possibilities compatible with the premises. It is not just a generalized effect of instruction, because it leads to a bigger improvement in reasoning than instruction in the use of suppositions. What remain open questions, however, are whether its effects are long lasting, and whether the method transfers to inferences, such as syllogisms, which do not depend on terms such as “if” and “or.”

Conclusions

To improve our thinking, it would help if we could cultivate a more capacious working memory and faster mental processes. On the assumption that neither of these goals is immediately accessible to teaching, a more modest goal – whether we are making inductive generalizations, formulating explanations, or inferring their deductive consequences – is the ability not to overlook a possibility. Above all, we need more imagination in envisaging what is possible: Julia may not be in Atlanta; the bow doors may not have been closed.

One way in which to improve thinking is to teach a full-fledged course in critical thinking, akin to what was taught in Venezuelan schools during the effort to increase the population’s intelligence (Nickerson, 1985). Such methods call for a major investment of resources, and the resulting skills may to be too time-consuming to use in daily life, especially in emergencies. Another way in which to teach thinking is to help students to learn to use diagrams that make it easy for them to think of possibilities. Still another approach is to teach individuals how to improve their thinking using procedures that take only minutes to learn, that are rooted in how they tend to think spontaneously, that require no apparatus – not even a paper and pencil, that have lasting effects, and that work for any domain. The model method may be a first step towards such a method.

References

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