The development of the reasoning brain and how to foster logical reasoning skills

The transition from concrete to abstract reasoning is challenging for children. Neuroscience is helping educators understand the difficulties children face and what might be done to support them.

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Executive summary

Learning to reason logically is necessary for the growth of critical and scientific thinking in children. Yet, both psychological and neural evidence indicates that logical reasoning is hard even for educated adults. Here, we examine the factors that scaffold the emergence of logical reasoning in children. Evidence suggests that the development of reasoning with concrete information can be accounted for by the development of both world knowledge and self-regulation. The transition from concrete to abstract reasoning, however, is a challenge for children. Children's development of reasoning may be supported by encouraging both divergent thinking and reasoning at levels of abstraction that are just above reasoners' current levels, alongside activities in which children reason with others.

Introduction

It is often argued that one of the most fundamental goals of education is to nurture critical thinking, that is, to teach children to employ good reasoning skills when developing their beliefs. Therefore, fostering logical reasoning should be an important goal for education: Children should learn to provide logical reasons for their opinions and should be able to distinguish between good and bad arguments. This is likely to be important for their effective exercise of citizenship as adults. For example, logical reasoning could tell you that it is unwarranted to conclude "All Muslims are terrorists" from the assertions "All the 9/11 perpetrators are Muslims" and "All the 9/11 perpetrators are terrorists." Yet, many educated adults still draw such a conclusion, most likely because fear and bias can overcome rational thinking. This suggests that logical reasoning is hard even for educated adults, a conclusion that is supported by a wealth of psychological studies. Perhaps the most striking demonstration of the difficulty of logical reasoning was discovered by the psychologist Peter Wason in 1966[1]. Wason designed a task in which he presented participants with four playing cards, each with a letter on one side and a number on the other side. For example, the cards could be as follow:

A B 2 3

Participants were then shown the conditional rule "If a card has the letter A on one side, then it has the number 2 on the other side." The task consisted of selecting those cards that had to be turned over to discover whether the rule was true or false. Since Wason's study, that task has been performed many times, and the results are always the same. Most people select either the A card alone or sometimes both the cards A and 2. However, very few adults, even highly educated, typically choose the 3 card. This is despite the fact that discovering what is on the other side of the 3 card is necessary to evaluate whether the rule is true or false (i.e., if there is an A on the other side of the 3, the rule is false). This reasoning failure has puzzled psychologists for decades because it questions the long-standing assumption that human beings are inherently rational. Why is it so hard for participants to select the 3 card? Neuroscience research suggests that it is because it is much more difficult for the brain to focus on the elements that are absent from the rule (e.g., 3) than on the elements that are present (e.g., A)[2]. Thus, selecting the 3 card requires much more extensive brain activation in several brain regions (primarily involved in attention and concentration) to overcome that tendency (see Figure 1). So, how can we get people to activate more of their reasoning brain and act more rationally on this task? One of the first ideas that comes to mind would be to teach them logic. Cheng and colleagues[3] have tested this. The researchers presented the Wason selection task to college students before and after they took a whole-semester introductory class in logic (about 40 hours of lectures). Surprisingly, they found no difference in the students' poor performance between the beginning and the end of the semester. In other words, a whole semester of learning about logic did not help students make any less error on the task! What, then, can train the reasoning brain? To answer that question, it is interesting to turn to what we know about the development of logical reasoning in children.

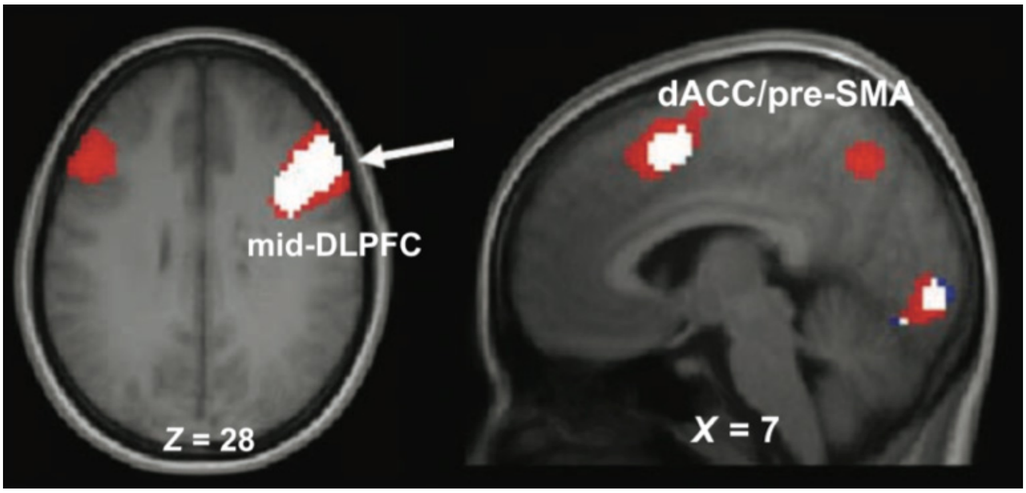

Figure 1. The reasoning brain. Location of the brain regions (in red, blue, and white) that are activated when participants reason with elements that are not present in the rule in the Wason card task. Activations are displayed on pictures of the brain taken using a magnetic resonance imaging scanner. (Reproduced from Ref. [2])

The development of concrete logical reasoning in children

It is clear that even young children can use some logical reasoning when concrete information is involved. For instance, most 6-year-olds can draw the conclusion “The person is hurt” from the statements “If the person breaks his arm, the person will be hurt” and “The person breaks his arm.” However, the reasoning abilities of young children are limited. For example, many 6-year-olds would also draw the conclusion “The person broke his arm” from the statements “If the person breaks his arm, the person will be hurt” and “The person is hurt.” This, however, is an invalid conclusion because there may be many other reasons why a person could be hurt. Children will progressively understand this and will make this type of reasoning error less and less as they get older. By the time they reach the end of elementary school, most children are able to refrain from concluding “The person broke his arm” from the statements “If the person breaks his arm, the person will be hurt” and “The person is hurt”[4]. Critically, this increased reasoning ability is mirrored by an increase in the ability to think about alternate causes for a given consequence. For example, older children are much more able than younger children to think about the many other reasons why someone would be hurt, like getting sick, breaking a leg, cutting a finger, etc. In other words, better reasoning ability with age is associated with a better ability to consider alternatives from stored knowledge. Clearly, however, children differ in terms of what they know about the world. This predicts that those who have better world knowledge and can think about more alternatives should be better reasoners than the others. And this is exactly what has been shown in several studies[4].

Interestingly, the importance of world knowledge for reasoning has a paradoxical effect: It can make children poorer reasoners on some occasions. For example, children who can think about a lot of alternatives would be less inclined to draw the logically valid conclusion “The person will be tired” from the statements “If a person goes to sleep late, then he will be tired” and “The person goes to sleep late.” This is because a child with significant world knowledge can think of several circumstances that would make the conclusion unwarranted, such as waking up later the next day. Thus, more world knowledge needs to be associated with more ability to suppress the alternatives that might come to mind if the task requires it. This self-regulation ability relies on a part of the brain that also massively develops during childhood, i.e., the prefrontal cortex (see Figure 2). Overall, then, the development of concrete logical reasoning in children can be largely accounted for by the development of both world knowledge and self-regulation skills that are associated with the frontal cortex.

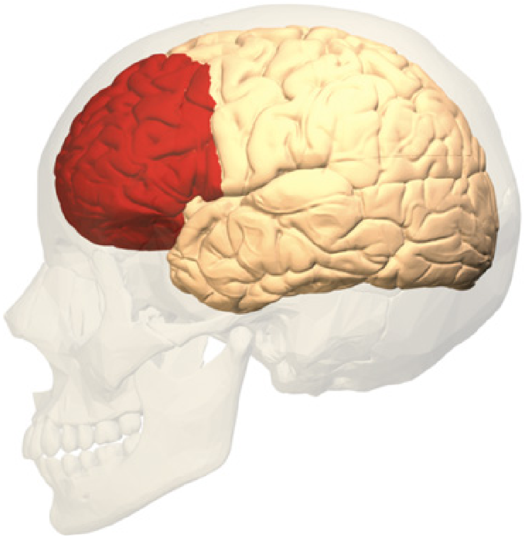

Figure 2. The prefrontal cortex. Location of the prefrontal cortex on a 3D rendering of the human brain. Polygon data were generated by Database Center for Life Science(DBCLS), distributed under a CC-BY-SA-2.1-jp license.

From concrete to abstract reasoning

There is, however, an important difference between the reasoning skills described above and the task developed by Peter Wason about the four cards. What we just described relates to reasoning with very concrete information, whereas the card task involves reasoning with purely abstract information. Abstract reasoning is difficult because it requires one to manipulate information without any referent in the real world. Knowledge is of no help. In fact, neuroscience research indicates that abstract and concrete reasoning rely on two different parts of the brain[5] (see Figure 3). The ability to reason logically with an abstract premise is generally only found during late adolescence[4]. Transitioning from concrete to abstract reasoning may require extensive practice with concrete reasoning. With mastery, children may extract from the reasoning process abstract strategies that could be applied to abstract information. A recent study, however, suggests a trick to help facilitate this transition in children[6]. The researchers discovered that abstract reasoning in 12- to 15-year-olds is much improved when these adolescents are previously engaged in a task in which they have to reason with information that is concrete but empirically false, such as "If a shirt is rubbed with mud, then the shirt will be clean." No such effect was observed when adolescents are asked to reason with concrete information that is empirically true, such as "If a shirt is washed with detergent, then the shirt will be clean." Therefore, reasoning with information that contradicts what we know about the world might constitute an intermediary step in transitioning from concrete to abstract reasoning.

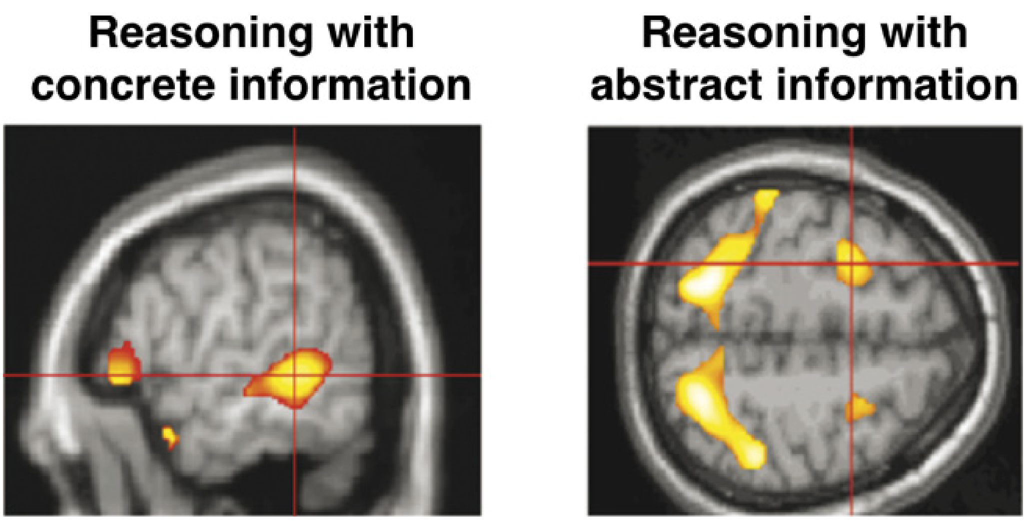

Figure 3. Brain regions activated when reasoning with concrete (left) and abstract (right) information. Activations are displayed on pictures of the brain taken using a magnetic

resonance imaging scanner. (Reproduced from Ref. [5])

What can we do to foster logical reasoning skills?

What, then, can we do to help foster the development of logical reasoning skills in children? The research described above suggests several potentially fruitful ways. First, it is clear that the development of concrete reasoning—the very first type of reasoning children can engage in—relies on an increased ability to think about counter-examples for a given statement. This implies that knowledge about the world is critical to the emergence of logical reasoning in children, at least when concrete information is involved. Therefore, all activities that would expand such world knowledge (e.g., reading informational books, learning new vocabulary, exploring new environments and places) are likely to be beneficial to the development of children's reasoning skills. Second, it is important to consider that the more world knowledge a child possesses, the more he/she will need to juggle with this knowledge. For example, generating counter-examples when solving a reasoning problem will require maintaining pieces of information in memory for a short period of time, a type of memory called *working memory*. World knowledge can also sometimes be detrimental to reasoning and needs to be *inhibited*, such as when recognizing that the conclusion "The person will be tired" logically follows from the statements "If a person goes to sleep late, then he will be tired" and "The person goes to sleep late" (even if one might think of several conditions that would make the conclusion untrue based on what we know about the world). Fostering these types of self-regulation skills (working memory and inhibition) should thus be beneficial to the development of logical reasoning. Several studies suggest that these functions could be promoted by targeting children's emotional and social development, such as in curricula involving social pretend play (requiring children to act out of character and adjusting to improvisation of others), self-discipline, orderliness, and meditation exercises[7]. Studies also indicate positive effects of various physical activities emphasizing self-control and mindfulness, such as yoga or traditional martial arts[7]. Third, studies indicate that the transition from concrete to abstract reasoning occurring around adolescence is challenging. Although more research is needed in this domain, one promising way to help this transition is by encouraging children's thinking about alternatives with content that contradicts what they know about the world (e.g., "If a shirt is rubbed with mud, then the shirt will be clean"). In sum, as stated by Henry Markovits, "the best way to encourage the development of more abstract ways of logical reasoning is to gradually encourage both divergent thinking and reasoning at levels of abstraction that are just above reasoners' current levels"[4].

Conclusion

Fostering the development of logical reasoning should be an important goal of education. Yet, studies indicate that logical reasoning is hard even for educated adults and relies on the activation of an extensive network of brain regions. Neuroscience studies also demonstrate that reasoning with concrete information involves brain regions that qualitatively differ from those involved in reasoning with more abstract information, explaining why transitioning from concrete to abstract reasoning is challenging for children. We nonetheless reviewed here the more recent research on the development of reasoning skills and suggest several important factors that scaffold children's reasoning abilities, such as world knowledge and self-regulation functions. On a final note, it is important to consider that logical reasoning is not something that we always do on our own, isolated from our peers. In fact, some have argued that the very function of reasoning is to argue with our peers (i.e., to find the best arguments to convince others and to evaluate arguments made by others)[8]. This idea is interesting from an educational point of view because it suggests that reasoning with others might be easier than reasoning in isolation—a hypothesis validated by several studies. For example, performance on the card task developed by Peter Wason is much higher when participants solve it as a group rather than alone[8]. Therefore, encouraging activities in which children reason with others might also be a fruitful avenue for stimulating the reasoning brain.

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