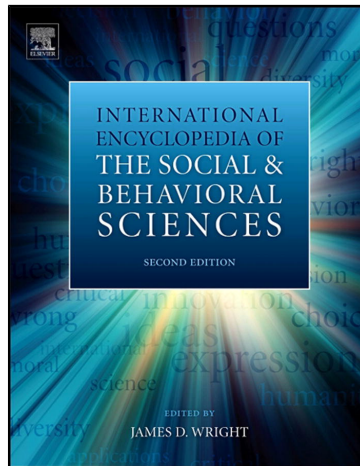


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## Logical and Hypothetical Reasoning in Adolescence, Development of

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### Abstract

This article examines the development of logical and hypothetical reasoning from early childhood through adolescence and young adulthood. These two forms of reasoning enable adolescents to entertain and coordinate deductively valid and ontologically possible propositions. The development of logical and hypothetical reasoning in adolescence involves both the construction of metalogical knowledge about logical necessity and truth and executive regulation of inferences for systematic thinking. A variety of biological, psychological, social, and cultural factors are known to influence developmental changes in such reasoning.

Adolescence is a time during which new and powerful forms of reasoning emerge, resulting in fundamental transformations in how people think about themselves, others, and the world. Central to adolescent progress is the ongoing development of logical and hypothetical reasoning (Amsel, 2011; Barrouillet and Gauffroy, 2013; Markovits, 2013). Logical reasoning, in its core meaning, is the deduction of conclusions that follow necessarily from given premises. Hypothetical reasoning is the process of creating, and making inferences about, possible worlds, such that (what is believed to be) reality can be compared to alternatives.

The significance of logical and hypothetical reasoning is that they allow the mind to go beyond perceptions of immediately available information to formally and systematically entertain deductively valid and ontologically possible propositions. These two inference skills are implicated in a range of uniquely human activities, from the make-believe play of children to the research practices of scientists. Both the pretending child and researching scientist have been characterized as generating hypothetical alternatives to the way the world is known or believed to be and reasoning logically about their implications and consequences.

The focus on adolescence as a period of major progress in logical and hypothetical reasoning needs justification in light of claims that these inference skills are applied spontaneously by toddlers or, quite the contrary, that they are acquired only with graduate training in science. In contrast to both these positions, Jean Piaget (1972) and Inhelder and Piaget (1958) proposed a qualitative transition in early adolescence (beginning about age 11 or 12 years) to a new stage of 'formal operations' involving advanced levels of logical and hypothetical reasoning. In this article, the authors review research generated over half a century that has supported and challenged Piaget's claims and tested alternative theoretical accounts. The review is organized chronologically, first addressing the roots of these reasoning abilities in young children, their increasingly sophisticated use by older children and young adolescents, the potential for increased control and coordination beyond that, and their promotion with formal education. The review also considers biological, psychological, social, and cultural factors associated with developmental changes in reasoning.

### Logical and Hypothetical Reasoning in Young Childhood

In their classic book, *The Growth of Logical Thinking from Childhood to Adolescence*, Inhelder and Piaget (1958) describe major advances in adolescents' ability to reason logically and hypothetically and explain these advances as outcomes of constructing the mental structures of the formal operational stage (Moshman, 2009). Formal operations is the fourth and final stage of cognitive development, when thinking transcends earlier constraints that limited understanding and inference to actions on the world (sensorimotor stage), symbolic representations of the world (preoperational stage), or formal relations (categorical, mathematical) applied to actual situations in the world (concrete operational stage). Inhelder and Piaget's conclusions were based on individual interviews of over 1500 children and adolescents, ages 5 through 16 years, as they solved a variety of physics problems. Their performance reveals an increasing depth of appreciation with age of the logical and mathematical features of the problems and their growing skills to solve them by systematically constructing hypothetical possibilities and inferring their logical consequences. This strict coordination of logical and hypothetical reasoning, which Piaget called hypotheticodeductive reasoning, was seen as central to formal operations.

The Piagetian focus on adolescence has been challenged by information processing theorists, for whom cognitive development in general and the acquisition of inference skills in particular can be explained by the regular and continuous improvement of cognitive processes of memory, attention, and executive control, among others. Information processing researchers have examined young children's logical and hypothetical inference skills to identify the nature of their underlying inferential competence and sources of development. For example, there is evidence that young children could successfully solve simple combinatorial reasoning tasks in which they were asked to generate all the six possible combinations of clothing for a teddy bear who had two tops and three pairs of pants (English, 1993). But there was a substantial decrement in children's performance when the cognitive demands of the task increased by adding more combinations to the two-variable problem ( $3 \times 3$ ) or by adding a third variable ( $2 \times 2 \times 2$  or

$2 \times 2 \times 3$ ). Only adolescents demonstrated inferential competence on the more complex combinatory tasks.

Similarly, there is evidence that young children can solve simple logical reasoning tasks in which they deduce a proposition  $q$  from a conditional (If  $p$  then  $q$ ) or universally qualified (all  $p$  are  $q$ ) major premise and the minor premise  $p$  (Hawkins et al., 1984; Kuhn, 1977). Their performance on these inference tasks is almost flawless when the content of the premises are congruent with that they know or believe (If the wind is blowing, the flag on the pole is waving; The wind is blowing; Is the flag waving?). However, their performance is below chance when the premise content is incongruent (All birds have wheels; Robin is a bird; Does Robin have wheels?) as such content increases the cognitive demands by requiring that children accept and reason from a disbelieved premise (hypotheticodeductive reasoning). Moreover, even using congruent content, children have more difficulty making the equally valid *modus tollens* inference (if  $p$  then  $q$  and not  $q \rightarrow$  not  $p$ ) compared to their performance on the *modus ponens* inference (if  $p$  then  $q$  and  $p \rightarrow q$ ), perhaps because of the additional linguistic demand of processing negations (Note: The expressions on the left of the  $\rightarrow$  are premises and the expression on the right is the conclusion, which may or may not be judged to follow logically from the premises) (Roberge, 1971).

Children also performed particularly poorly when required to inhibit inferences due to an invalid argument, as in the cases of standard fallacious arguments that assert the consequent (if  $p$  then  $q$  and  $q \rightarrow p$ ) or deny the antecedent (if  $p$  then  $q$  and not  $p \rightarrow$  not  $q$ ). Invalid inferences are often made because of a failure to distinguish a conditional premise (if  $p$  then  $q$ ), where  $p$  is a sufficient but not necessary condition for  $q$ , from the biconditional premise (if and only if  $p$  then  $q$ ) where  $p$  is both necessary and sufficient for  $q$  and thus  $q$  is also necessary and sufficient for  $p$  (Rumain et al., 1983). Children were shown to inhibit invalid inferences when presented with multiple premises (if  $p$  then  $q$ , if  $a$  then  $q$ , if  $b$  then  $q$ ), which highlight that a given antecedent condition ( $p$ ) is not the only one sufficient for consequent ( $q$ ), countermending the invited inference that  $p$  is also necessary for  $q$  (Rumain et al., 1983). Other research demonstrates that children's performance on conditional reasoning tasks with the premise if  $p$  then  $q$  improves if they are asked to generate examples of other sufficient conditions for  $q$  in the form of instances of not  $p$  and  $q$  (Markovits, 2013).

Other cases abound of researchers seeking to demonstrate young children's inferential competence. In one line of research, young children have demonstrated the ability to make inferences from premises with incongruent content when they are presented in a pretend context (Amsel et al., 2005b; Dias and Harris, 1988). For example, when the premises *all cats bark* and *Rex is a cat* was presented as part of pretend play activity, 6-year-olds affirmed that *Rex barks* at a rate above chance (Dias and Harris, 1988). Framing empirically false premises as 'pretend' invites children to use their imagination and create a fanciful make-believe world from which they suppose the truth of the premise and infer causes and consequences of the pretend states of affair (Harris, 2000). Make-believe worlds are fanciful in the sense that they are not constrained by and should have no influence on understanding the real world (Leslie, 1987). Young children generally respect this by

carefully distinguishing between fantasy and reality, limiting cases where the former impacts the latter (Weisberg, 2013).

Despite limitations in their information processing capacities, young children demonstrate logical and hypothetical inference skills, at least in certain contexts. But most developmentalists, following Piaget, believe logical and hypothetical reasoning continue to develop at least through early adolescence (Amsel, 2011; Barrouillet and Gauffroy, 2013; Klaczynski, 2009; Kuhn, 2009; Markovits, 2013; Moshman, 2011, 2013a), although differing with Piaget and with each other about the details of this developmental transition.

### Logical and Hypothetical Reasoning in Older Children and Young Adolescents

Although even young children have logical and hypothetical competencies, older children and young adolescents demonstrate increasing insight about and flexibility in use of these inference skills across different contexts. For example, Andrew Shulman and Susan Carey (2007) examined the development of judgments about ontological possibilities with 4-, 6-, and 8-year-olds, and college students. Participants were asked to judge whether ordinary (eating chocolate ice cream), improbable (eating pickle ice cream), and impossible (eating lightning) events could occur in real life. Only the college students judged ordinary and improbable events as equally possible, distinguishing them from impossible events. The ability to distinguish improbable from impossible events improved over age as children relied less on whether these events were experienced and more on identifying real-world facts that would preclude impossible events from occurring. The growing capability of older children to reflect on and imagine the real-world status of nonexperienced events was found to generalize across different types of impossible and improbable biological, psychological, and social events (Shulman, 2009).

The ability to reflect on the ontological status of events is implicated in counterfactual reasoning about states of affairs that could have occurred but did not. Counterfactual reasoning requires the formation of serious possible worlds, which – unlike fanciful make-believe ones – are constrained by reality and can be used to compare it to possible alternatives. Although creating mental worlds of any sort requires the work of the imagination (Harris, 2000), possible worlds can be much more challenging to create than are make-believe ones because of the need in the former to reflect on and evaluate event sequences as ontologically plausible (Amsel, 2011).

Counterfactual reasoning can have emotional consequences of regret upon the realization that one could have acted differently in a situation and thereby avoided an undesirable outcome that has occurred. Although there has been some controversy about when regret is first experienced and judged in others (Rafetseder and Perner, 2012), anticipating potential future regret and taking actions to avoid it appears to develop only in adolescence (Amsel et al., 2005a; Guttentag and Ferrell, 2008).

The greater insight into and flexibility in the use of inference skills by young adolescents is further illustrated in logical reasoning. Older but not younger children distinguish deductive from inductive inferences on the basis of the certainty

associated with the former, an insight that appears to develop further in adolescence (Pillow et al., 2010). Furthermore, young adolescents but not children can explicitly distinguish arguments by their logical validity (e.g., spontaneously categorizing argument 1 as logically valid but argument 2 as logically invalid) irrespective of the truth of the conclusions (Moshman and Franks, 1986).

1. If dogs are bigger than elephants, and elephants are bigger than mice, then dogs are bigger than mice.
2. If dogs are bigger than mice, and elephants are bigger than mice, then dogs are bigger than elephants.

The initial emergence of explicit distinctions between deductive and inductive inferences and between valid and invalid arguments in early adolescence has been characterized as part of a broader acquisition of metalogical knowledge (Moshman, 2011). Metalogical knowledge is explicit conceptual or epistemological understanding about the justifiability of inferential processes and the necessary (as distinct from empirical) nature of logical truth. Correct use of inferential skills is no guarantee that the meaning and significance of the inferences are appreciated or that their justification is understood. The dramatic advance of metalogical understanding in early adolescence is likely associated with the increase in other inference skills demonstrated on logical reasoning tasks. For example, young adolescents no longer need the support of a pretend play context in order to mentally disregard their prior beliefs and knowledge and correctly infer conclusions in conditional reasoning with incongruent premises (Amsel et al., 2005b).

The emergence of increasingly explicit knowledge about logic and reasoning can be attributed most directly to active reflection on inferential processes, including abstraction of their logical form and construction of advanced conceptions of necessity and possibility. Such reflection generally occurs in social contexts of argumentation and justification and is likely influenced by a variety of biological and cognitive factors. For example, brain changes in adolescence are associated with increases in working memory and cognitive control (Paus, 2005) and may enable the construction of higher order metalogical knowledge.

In addition to biological and cognitive considerations, there are also changes in the schooling of older children and young adolescents, at least in cultures with compulsory education. Middle or Junior High school students (grades 6–8 or 7–9) have a much more rigorous curriculum than younger students. Notably, for many, postelementary education is their first exposure to algebra and geometry. Mathematical instruction in these topics has been shown to be related to improvements in students' formal concepts of justification, proof, and equivalence (Alibali et al., 2007; Bieda, 2010), which may also have consequences for their thinking about their own reasoning and, more generally, about the logical nature of mathematics as distinct from empirical matters of science.

Finally, culture itself, and the value it places on higher ordered thinking, may play a role in older children's and young adolescents' tendency to think about their reasoning. Cross-cultural researchers argue that the acquisition and use of higher ordered inference skills depends on whether or not a given culture views them as useful (Cole, 2006). For

example, traditional villagers in third-world cultures resist attempts to get them to engage in the simplest forms of logical reasoning when the premises are not known to be true (Luria, 1976). Consider the dialogue between Alexander Luria (a Russian psychologist) and a rural Uzbekistan farmer (Luria, 1976: pp. 108–109). Luria presented the following logical argument: In the Far North, where there is snow, all bears are white. Novaya Zemlya is in the Far North and there is always snow there. What color are the bears there? The Uzbekistan adult replied, "There are different sorts of bears." Luria then repeated the syllogism, and the farmer responded: "I don't know. I have never seen any others...Each locality has its own animals: if it's white, they will be white; if it's yellow, they will be yellow." Luria continued: "But what kind of bears are there in Novaya Zemlya?" The farmer replied: "We always speak only of what we see; we don't talk about what we haven't seen."

In summary, early adolescence is marked by advances in metalogical knowledge and in its use to guide logical and hypothetical reasoning. Inferences come to be intentionally deployed in the service of critically evaluating the logical consistency and ontological plausibility of claims made about the real world. Reasoning, which can be defined as epistemologically self-regulated thinking (Moshman, 2013b), becomes increasingly reflective in its orientation toward justifiable conclusions. This is a notable development beyond the child's use of logical and hypothetical inference skills to create and reason within alternative make-believe worlds.

The progression from fantasy to formality in the scope of reasoning is consistent with the Piagetian account of development. It remains unclear, however, whether all individuals in all cultures achieve something like formal operations. The rural Uzbekistan farmer made famous by Luria gives perspective on the importance of the biocultural context on the development of inference skills. Rather than being intrinsically driven to construct metalogical knowledge or to refine their inference skills in light of such knowledge, adolescents and adults may come to do so because of the biocultural context in which they grow up. The complex interactions between the society, schooling, and social context of young adolescents as they themselves go through the hormonal changes associated with puberty affect their acquisition of inferential skills. In a biocultural context that is supportive of the acquisition of metalogical knowledge and the refinement of logical and hypothetical reasoning skills, inferential abilities reach levels not seen in childhood and may continue to develop well beyond early adolescence.

### Further Development of Logical and Hypothetical Reasoning in Adolescence

Many individuals demonstrate improvements in logical and hypothetical reasoning beyond early adolescence. Hypothetical thinking improves as adolescents become capable of making more complex inferences about alternative possible worlds on counterfactual reasoning tasks. For example, Ana Rafetseder and her colleagues presented counterfactual reasoning tasks requiring simpler and more complex inferences (exemplified below) to 6-, 10-, and 14-year-olds and adults (Rafetseder et al.,

2013). Researchers acted out stories with dolls and props and carefully checked participants' understanding of the details of each story before asking the counterfactual question, which in the versions below was "What would have happened if Suzi had taken her shoes off? Would the floor be clean or dirty?" Overall correct performance was much lower on the more complex version 2 (the floor would be dirty, 64%) than on the simpler version 1 (the floor would be clean, 98%) story. Version 2 requires mentally inferring a complex counterfactual outcome in which Suzi keeps the floor clean but Max dirties it when he subsequently walks through it. Only the adults performed equally well on both versions; 14-year-olds showed a very high level of correct performance but still performed better on the simpler version 1 than on the more complex version 2 story. The 10- and 6-year-old children performed significantly worse than the 14-year-olds and adults, with approximately 50% not making a single correct response on version 2 stories. The authors concluded that there remain challenges in creating possible worlds that extend into adolescence.

Version 1. One day the floor is nice and clean, but then something happens. Suzi comes home and does not take her shoes off and makes the floor all dirty.

Version 2. One day the floor is nice and clean, but then something happens. Suzi and Max come home and they do not take their shoes off. Suzi walks in (followed immediately by Max as depicted by dolls) and makes the floor all dirty.

Logical thinking also improves as adolescents become better able to make deductive inferences on abstract conditional reasoning tasks. These tasks provide no knowledge-based counterexamples to support a sufficiency relation between antecedent and consequent. For example, [Henri Markovits and Hugues Lortie-Forgues \(2011\)](#) had participants aged 12 and 15 years make inferences about abstract conditionals (e.g., if a person daigues then they will become a gadoro), which were presented as conditions on the planet Kronus, where there were different names for things than on Earth. The older group outperformed the younger, on average, particularly when resisting making invalid inferences on denying the antecedent and asserting the consequent items. Such errors would be expected if participants assume a necessary and sufficient relation between the abstract antecedent and consequent. These and other results suggest that abstract understanding of conditional premises as sufficient relations between antecedents and consequents may continue to improve at least through age 15 years ([Markovits, 2013](#)).

These changes in reasoning documented above occur as part of a broader set of cognitive changes affecting adolescents ([Kuhn, 2009](#)). For example, problem solving can be performed more quickly and efficiently by adolescents than by children because a larger range of relevant experiences, knowledge, and heuristics (simplified inference strategies or 'rules of thumb' that lead to quick but sometimes incorrect conclusions) can be automatically activated in memory ([Reyna and Farley, 2006](#)). However, the unique challenge of ontologically complex and logically abstract inferences is to inhibit automatically activated knowledge, experiences, and heuristics in favor of making carefully controlled inferences that are intentionally guided by

metalogical knowledge. That is, although metalogical knowledge aids in adolescents' understanding what inference to make, adolescents need to exercise executive control over their information processing system in order to make such inferences free from bias resulting from automatically activated experiences, knowledge and heuristics.

It is notable then that middle adolescence is for many a period of improvements in executive function, which is a "deliberate top-down neurocognitive process involved in the conscious, goal-directed control of thought, action, and emotion" ([Zelazo and Carlson, 2012](#): p. 354). The improvement of executive function is linked to neurological changes in the speed and efficacy of neurons in a specific area of the brain's prefrontal cortex and their connections to other brain areas ([Blakemore, 2012](#)). Changes in executive function are thought to better enable middle adolescents to inhibit automatic processes and to rely instead on more controlled and deliberate processes in order to make intentional inferences that are guided by metalogical knowledge. Direct and indirect measures of prefrontal cortex functioning have been shown to be related to correctly resolving conflicts between activated beliefs about the truth versus the logical validity of conclusions on logical reasoning tasks ([Steege and De Neys, 2012](#); [Stollstorff et al., 2012](#)).

In addition to executive function and other information processing abilities necessary for improved inferential skills, many adolescents continue to construct metalogical knowledge and increasingly use it to guide their inferences. More broadly, adolescents' reasoning reflects their developing epistemologies, which address the nature of and foundations for their own and others' knowledge claims about the world, especially with respect to normative issues of truth and justification. Many adolescents become increasingly focused on whether knowledge claims are best treated as objective statements that are either factually true or validly deduced, subjective tastes that are merely more or less preferred, or reasonable interpretations that can be rationally evaluated as convincingly justified ([Chandler et al., 1990](#); [Kuhn, 1991, 2009](#); [Kuhn et al., 1988](#); [Moshman, 2011, 2013b](#)).

Besides changes at the personal level, there are also changes at the interpersonal level that contribute to adolescent reasoning, including disputes and disagreements with peers and parents. Effective argumentation requires coordinating hypothetical and logical reasoning by highlighting the quality (strengths and weaknesses) of logically possible justifications of knowledge claims ([Clark and Sampson, 2008](#); [Kuhn, 1991](#)). Furthermore, argumentation implicates both (1) the availability of metalogical knowledge about the quality of arguments and (2) inferential skills to strategically apply that knowledge in ongoing arguments to defend one's own and undermine one's opponent's positions. Argumentation skills have been shown to improve from childhood to middle adolescence in both ways. For example, 11th grade adolescents, who on average had more sophisticated epistemological understanding than their 7th and 9th grade counterparts, were also generally better able to detect informal reasoning fallacies than younger students ([Weinstock et al., 2006](#)). Similarly, adolescents improve in understanding the need to strategically undermine their opponents' positions and not just to defend their own positions ([Kuhn and Udell, 2007](#)), although they

may not always implement such a strategy (Stanovich et al., 2012). Finally, argumentation has been shown to improve with practice, particularly with interventions that help arguers reflectively assess the quality of their performance (Chinn and Anderson, 1998; Iordanou, 2010; Udell, 2007). However, cultural variation exists in the perceived value of argumentation as a mean of promoting cognitive development or educational outcomes (Kuhn et al., 2011).

At the societal level, high school education may contribute to improving metalogical understanding of and skills for inferential reasoning. The increased premium placed on STEM (Science, Technology, Engineering, and Mathematics) preparation has resulted in instruction promoting students' abilities to engage in scientific practices (NRC, 2012). Like argumentation, the forms of reasoning practiced by scientists necessitate the coordination of logical and hypothetical reasoning by focusing on generating hypotheses, designing experiments, and evaluating evidence (Inhelder and Piaget, 1958; Kuhn et al., 1988). Proficiency in scientific reasoning involves both the metalogical understanding of formal theory–evidence relationships and skills to apply such understanding to the tasks of formulating and testing hypotheses and evaluating evidence.

Although children have been shown to have a variety of scientific reasoning skills (Morris et al., 2013), evidence points to further improvements beyond childhood and often well into adolescence. Among these improvements are increases in metalogical and epistemological understanding of scientific reasoning and in associated inferential skills. Metalogical developments include more carefully delineated distinctions between theory and evidence, particularly in the forms of evidence that would uniquely test theoretically based hypotheses (Bullock et al., 2009; Kuhn et al., 1988). Epistemological developments include insights into the nature of scientific knowledge, such as recognizing the tentativeness of empirical (as distinct from logical) claims (Sandoval, 2005). There are also corresponding improvements from childhood to adolescence in skills to minimize inferential biases in scientific reasoning. These 'debiasing' skills include reducing the effect of prior beliefs in the evaluation of evidence, generating and evaluating a broader set of possible hypotheses, generating disconfirming and unconfounded tests of hypotheses, and keeping accurate and systematic records (Amsel and Brock, 1996; Klahr et al., 1993; Kuhn et al., 1995; Schauble, 1990, 1996). Although scientific reasoning has been shown to improve with practice and instruction (Kuhn et al., 1995; Schauble, 1996), metalogical understanding of and skills for making unbiased inferences remain less than optimal.

In summary, both logical and hypothetical reasoning tend to become more sophisticated over the course of adolescence, not only when inferences are made individually but also when the two are coordinated, as in argumentation and scientific reasoning. This reflects a developmental trend toward consolidation in the sense that reasoning is better guided by increased metalogical understanding of the logical validity and ontological consistency of inferences and more effectively controlled by an increasingly powerful information processing system. The more powerful information processing system enables the activation and use of justified inference strategies and the corresponding inhibition of automatically activated but potentially biasing experiences, knowledge, and heuristics.

But the powerful cognitive tendency to respond automatically remains, resulting in biased reasoning, even when one has metalogical knowledge of valid alternatives. Dual process theoretical accounts of reasoning explain how inferences may be biased by automatically activated information and also identify conditions under which one more readily deploys metalogical knowledge to foster valid reasoning (Amsel et al., 2008; Barrouillet and Gauffroy, 2013; Klaczynski, 2009; Stanovich et al., 2012).

These developments in reasoning beyond early adolescence are neither universal nor inevitable. They are a product of complex interactions among many factors, including cognitive reflection and self-regulation, preferences for deliberative reasoning, neurological functioning, interpersonal interactions, schooling, and cultural context.

### Educational and Professional Contributions to Logical and Hypothetical Reasoning

As noted previously, the trajectory of logical and hypothetical reasoning is affected by educational experiences. This effect becomes more pronounced over age. For example, college-educated adults are better able than non-college-educated adults to ignore their prior beliefs about a causal relation and validly evaluate data that contradict those beliefs (Amsel and Brock, 1996; Kuhn et al., 1988). A similar effect of education has been found for argumentation, with a college education related to improved performance on a variety of measures of argumentative skills (Kuhn, 1991), including a reduction of the so-called *myside bias*, a preference for supporting one's own position over opposing one's opponent (Toplak and Stanovich, 2003).

An intriguing suggestion of the effect of education on reasoning was provided by Demetriou and Bakracevic (2009), who presented conditional reasoning tasks to adolescents (13–15 years of age) and groups of young (23–25 years of age), middle (33–35 years of age), and mature (43–45 years of age) adults who had or had not completed college. The college educated adult groups made more correct responses than the non-college-educated adult groups, with adolescents scoring lower than the educated adults and higher than the noneducated adults. College-educated adults also were more certain of their answers than non-college-educated adults or adolescents, perhaps reflecting their greater understanding of the logical necessity of the inferences they were making.

The authors concluded that education had a beneficial effect on inference skills and understanding. Their data, however, do not rule out the alternative interpretation that students with greater reasoning abilities are simply more likely to successfully complete college. Darrin Lehman and Richard Nisbett (1990) provided stronger evidence for the causal effect of schooling on reasoning as part of a research program exploring the trainability of reasoning. College freshman in the Natural Sciences, Humanities, Social Science, and Psychology were given tests of probabilistic reasoning (requiring hypothetico-deductive inferences) and conditional reasoning (requiring deductive inferences). Although no different in their reasoning skills as freshmen, these students were retested as seniors to assess the changes in their reasoning over time. Students in the natural

sciences and humanities improved substantially in conditional reasoning compared to those in social science and psychology. At least for the natural science students, this improvement was related to the number of math and computer science courses taken, which require understanding abstract formal relations. Students in the social sciences and psychology improved substantially in probabilistic reasoning compared to those in the natural sciences and humanities, which was related to the number of statistics courses taken.

The impact of schooling also applies to professional training in science and the law leading to expertise in forms of logical and hypothetical reasoning. Expertise in science involves acquiring both general hypothetico-deductive inference abilities (e.g., designing simple and direct tests of hypotheses and drawing valid conclusions about theories in light of the evidence) and specific knowledge about the phenomenon of interest (e.g., knowing which variables may be possible causes and how best to test them). One study compared practicing scientists (experts) and college students (novices in how they designed tests in a computer simulation of the causes of the memory spacing effect – that better memory results when studying is spaced over time than massed together (Schunn and Anderson, 1999)). Half the experts were psychology researchers in cognitive psychology and so were domain experts and the other half were psychology researchers in other domains and so were task experts. Half the novices had high mathematics SAT scores (high ability novices) and half had average scores (average ability novices). The results demonstrated that there were specific knowledge differences between the domain experts and all other groups. However, the two expert groups made valid hypothetico-deductive inferences more often than the two novice groups. The results suggest that scientists are experts in general hypothetico-deductive reasoning and can apply it outside their immediate domain of expertise.

Another study of professional training in law and psychology demonstrated a similar generality in inferential expertise. Amsel et al. (1991) compared novices and experts in law and psychology in how they evaluate everyday causal statements (e.g., 'kicking the television (TV) set fixed the picture'). As experts in science, psychologists and psychology graduate students tended to make causal inferences more often than experts in law by appealing to statistical evidence of the association between the cause and the effect (e.g., every time the TV is kicked the picture is fixed). As experts in law, lawyers and law students tended to make causal statements more often than experts in science by appealing to counterfactual states of affair (e.g., if the TV had not been kicked it would not have been fixed). The novice groups (police officers and psychology undergraduates) tended not to find the statistical or counterfactual justifications particularly convincing and preferred to make causal statements by appealing to physical mechanisms (e.g., by kicking the TV, the connection between the wires got better).

## Conclusion

Children's logical and hypothetical reasoning become increasingly epistemologically self-regulated due to the development of metalogical knowledge and information processing skills,

a process that often continues well into adolescence and sometimes beyond. This developmental trajectory is the product of a broad set of factors ranging from biology to culture and includes a central role played by the individual's own motivated search to understand the epistemological basis for valid inference. Logical and hypothetical inferences increasingly come under metacognitive control, and this process may continue for older adolescents and adults who select experiences like attending university and professional school where they acquire expertise in the use of advanced reasoning skills. Logical and hypothetical reasoning is a life span phenomenon: It is present in young children in a variety of forms and continues to be refined well into adulthood in other forms. However, adolescence is a time of especially great developmental importance and potential in the development of such reasoning.

*See also:* Childhood and Adolescence: Developmental Assets; Counterfactual Reasoning, Qualitative: Philosophical Aspects; Deductive Reasoning Systems; Epistemic Doubt During Adolescence; Piaget's Theory of Cognitive Development; Piaget's Theory of Human Development and Education; Piaget, Jean (1896–1980); Practical Reasoning: Philosophical Aspects; Problem Solving and Reasoning: Case-based; Stress in Adolescence: Effects on Development.

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