The Handbook of Rationality

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15.1 The Development of Basic Human Rationality

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Summary

Understanding how rationality develops through childhood to adulthood is important for both theoretical and practical reasons. However, existing theories provide very different and seemingly conflicting descriptions, with some postulating the existence of very early forms of biologically based rationality, while others describe a long developmental process leading to explicit principles guiding rational thought. In this chapter, these different approaches will be described. An initial distinction is made between explicit, metacognitive forms of rational thinking and the implicit structure of inferences. Within each, theories and data that describe the developmental course of reasoning are analyzed. While it is not possible to point to a clear synthesis, the continual interaction between empirical knowledge and logical reasoning is a consistent component in all of these approaches.

1. Understanding the Development of Rationality

Development is generally characterized by progression from simple to more complex forms of cognitive functioning, with or without the aid of biological underpinnings. By analogy, one might expect children to become increasingly more rational. But this is far from universally supported. As with the adult literature, there is little consensus about the nature of rationality either in a broad or in a more restricted sense. The different developmental approaches that will be examined here, while seemingly divergent, indicate the complexity of the underlying developmental trajectory. As will be seen, the existence of irrational behavior in adults is coupled with evidence of forms of logical reasoning in very young children. Minimally, attempting to trace the development of rational thinking must require incorporating different systems, which might well have very different developmental paths.

Understanding the development of rationality is further complicated by the difficulty of clearly defining what rationality is in adults and even more in children. This is in fact the aim of many of the chapters in this handbook, and it would be impossible to repeat these arguments in a developmental context. However, most developmental studies that have looked at rationality specifically examine the ability of children to make inferences or judgments that correspond to standard logical norms, and for the purposes of this discussion, we will mostly use this general definition (for a broader perspective, see chapter 2.4 by Fiedler, Prager, & McCaughey, this handbook). However, even with this relatively straightforward definition, there is little consensus as to how, or even whether, the ability to make rational judgments develops. This inconsistency is probably most clearly shown by the existence both of theories that project clear developmental increases in children's rationality and of theories that suppose that even adults are not rational. In addition, developmental studies have examined very different phenomena, which are often difficult to compare. However, we can make one useful distinction that reflects different ways of examining this question. Specifically, we can distinguish between explicit and implicit rationality. The former refers to the study of the reasons that people give either to justify their own inferences or to explicitly account for differences in the level of adequacy of different forms of inference. The latter refers to the logical adequacy of judgments or inferences that people actually make.

2. The Development of Explicit Rationality

The study of the development of explicit rationality has two major poles, metalogical and argumentation.

2.1 Metalogical Development

"Metalogic" refers to the ability to think about one's own reasoning processes and can be seen as a subset of more general metacognitive processes (Flavell, 1979). The most direct theory describing the development of reasoning abilities is Moshman's account of reasoning

(Moshman, 1990, 2004, 2013; Moshman & Franks, 1986). Moshman makes a distinction between the implicit processes that are used to make specific inferences (which will be discussed later) and rationality, which can be defined as the ability to explicitly represent higher-level metalogical components of reasoning, such as concepts of inferential validity and logical necessity (Christoforides, Spanoudis, & Demetriou, 2016; Demetriou, Spanoudis, & Shayer, 2014; Moshman, 2011; Moshman & Franks, 1986). Metalogical understanding is the result of self-reflective processes that allow the abstraction of general principles from more specific forms of inference. In other words, rationality is developed through thinking about implicit inferences, by the reasoner trying to understand why these inferences are good or bad. The process is conceived of as a continuous one, leading to complex forms of epistemological understanding whose development goes well through adulthood (Hallett, Chandler, & Krettenauer, 2002) but with no necessary endpoint. More specifically, Moshman (2014) defines reasoning as involving inferential processes within the more general constraints of a metacognitive understanding of the goals and aims that animate a reasoner. Such forms of reasoning are inherently contextual, with the criteria defining "good" reasoning varying according to the domain in question. In other words, inferential processes are cognitive tools in the service of broader metacognitive goals and understanding, that is, rationality comprises the broader principles that guide specific inferences. Both the cited empirical studies and theoretical underpinnings suggest that with this definition, rationality undergoes an ongoing developmental process, such that the ability to be rational increases with experience and age. The clear emphasis on reasoning as inferences under metacognitive control thus suggests that rationality is late-developing, since it requires fairly complex forms of metacognitive understanding. Evidence of early forms of logical inference are simply building blocks in a complex developmental progression. For example, young children can consistently go from premises of the form "If *P* then *Q*; *P* is true" to correctly infer "*Q* is true" but do not necessarily understand why this inference is necessary. The basic metalogical understanding of the notion of logical necessity (i.e., to explicitly distinguish between empirical truth and validity) undergoes a clear developmental increase and is not typically shown before 10 to 12 years of age (Moshman & Franks, 1986).

There is one important question that is left unanswered by this theory, which is the relationship between rationality and inferential reasoning. Moshman's approach suggests that inferential processes are guided by metacognitive analyses. Indeed, one would expect a stronger relationship, so that the increased metacognitive awareness of the characteristics of reasoning that underpins the development of rationality should have a clear effect on the nature of the inferential processes that are used. There are almost no empirical data in a developmental context that addresses this question. It is worth citing recent work by Thompson (Newman, Gibb, & Thompson, 2017; Thompson, Prowse Turner, & Pennycook, 2011) that has examined the relationship between explicit degree of confidence in the rightness of judgments, which is one evaluation of metacognitive processes, and their logicality in adults. In fact, this work has found very little relationship between the two and certainly suggests that explicit metacognitive judgments do not necessarily correlate with the extent to which actual reasoning is logical (although see Markovits, Thompson, & Brisson, 2015). Thus, although it is very clear that the ability to explicitly analyze reasoning in terms of logical components develops in a consistent manner, it is less clear that rationality defined in this manner has a specific impact on actual judgments.

2.2 Argumentation

Another important form of explicit understanding that shows clear developmental patterns is derived from the notion of argumentation (see also chapter 5.5 by Hahn & Collins, this handbook). "Argumentation" refers to the way that specific inferences and accompanying justifications can be marshaled in order to either support a point of view or dispute an alternative viewpoint (Perelman, 1971). Ideally, argumentation skills allow a conscious weighting of the relative logical strength of different forms of inference, which can be seen as a building block for rationality. More important, argumentation requires an interaction between people having different points of view. Although it is possible to conceive of argumentation as an essentially one-way process (Mercier & Sperber, 2011), or a Vygotskian interaction between an adult and a child (Berk & Winsler, 1995), a stronger developmental viewpoint would suggest that the continual confrontation between opposing forms of inference would generate some form of metacognitive resolution of the resulting conflict. In fact, this form of interaction places the role of argumentation within the general context of social constructivism (Doise & Mugny, 1981), which suggests that the social confrontation of different points of view may be a critical component of cognitive development in general. There are in fact several studies that have shown the beneficial effect of interactions between children of different cognitive levels on basic Piagetian concepts (Ames & Murray, 1982; Murray, 1972). Such interactions have been shown to improve individual levels of logical reasoning (Moshman & Geil, 1998). More specifically, Kuhn and colleagues have shown that argumentation skills have a clear developmental trajectory (Kuhn, 1991, 1993; Kuhn & Udell, 2003). Promoting argumentation within the context of a collaborative social context produces a clear improvement in the ability of individuals to use argument strategies of increasing sophistication (Crowell & Kuhn, 2014; Kuhn & Crowell, 2011; Kuhn, Zillmer, Crowell, & Zavala, 2013). In other words, this general approach considers that rationality is a natural end state of a process by which different forms of arguments are directly confronted. This in turn supposes, consistent with the general tenets of social constructivism, that such a confrontation allows explicit acknowledgment of arguments that are logically superior and promotes metacognitive development leading to a more explicit understanding of what *makes* arguments logically superior.

As with the metalogical conception of rationality, this conception of argumentation sees it as a developmental process that acts on explicit representations, one that produces a consistent evolution toward greater rationality. However, it is also worth noting that a recent approach to argumentation proposed by Mercier and Sperber (2011) suggests a more unilateral conception with a variable relationship to rationality. They suggest that argumentation has evolutionary underpinnings for which the main aim is to achieve a form of dominance, by convincing others of the strength of an individual's point of view. In fact, this approach suggests that logical reasoning has evolved in order to support argumentation and that logic and rationality are rhetorical devices intended to construct an individual point of view strong enough to overcome other arguments (Mercier, 2011a, 2011b). Within this general perspective, rationality is seen as a skill that can be deployed or not, depending on the specific aims and context. There is some evidence that supports this point of view. For example, Klaczynski (2001) asked adolescents to evaluate arguments in terms of their logical adequacy. Older adolescents were quite good at picking out logical inconsistencies in relatively neutral arguments. However, where the same inconsistencies were used to support conclusions for which these adolescents had emotional beliefs, they tended very strongly to consider these arguments to be logically appropriate.

Both metalogical and argumentative approaches consider that there is a clear developmental progression in the ability of children and adolescents to explicitly consider the logical status of inferences and arguments. Both see this progression to be long and relatively difficult, suggesting that rationality requires a long developmental sequence. One major difference between these two points of view is the locus of this development. Moshman's approach suggests that metacognitive control and understanding is essentially an individual process, mediated by thinking about the structure of inferences. The notion of argumentation, by contrast, suggests that the development of an explicit rationality is the product of an ongoing process of social interaction. However, in both cases, there are reasons to believe that the kinds of inferences and judgments that people make are not fully accounted for by their explicit understanding.

In fact, there is a great deal of evidence that the inferences people actually make are highly variable. Both of the approaches that we have examined clearly suggest that there is an ongoing developmental progression in the abilities of people to consciously understand the basic principles underlying explicit rationality. If this was accompanied by a corresponding control of the actual inferences and judgments that people make, then we would expect a clear developmental progression in the nature of the inferences that were made, with adults showing a clearly consistent pattern of rational judgments. However, there is a great deal of empirical evidence that adults are much less rational in their judgments than one would expect from such a point of view. Both the biases-and-heuristics program of Tversky and Kahneman (2004) and more current dual-process theories (Evans & Stanovich, 2013; Sloman, 1996) have clearly shown that people's judgments and inferences are far from logically appropriate. In fact, much of the research on the development of reasoning has examined what kinds of inferences people make irrespective of their explicit reasons, with the idea that the structure of these inferences gives an implicit picture of the underlying level of rationality.

3. The Development of Implicit Rationality

Before examining the different developmental theories that have attempted to explain how inferential reasoning develops in children and adolescents, it is useful to present the general interplay between logic and knowledge, which has been one of the key debates in this field. As mentioned previously, research on reasoning in adults has shown a remarkable level of what can be construed as irrationality. Although there are many factors underlying these effects, one of the more important of these is the strong influence of people's knowledge and beliefs on the inferences that they make. This has led some current theorists to suggest that classical "logic" may not be the best model to understand the adequacy of people's reasoning but that some form of Bayesian probability calculus might be better adapted to the reality of human reasoning (e.g., Evans, Over, & Handley, 2005; Oaksford & Chater, 2007; see also chapter 4.5 by Chater & Oaksford, this handbook). In other words, rationality might be construed as the ability to reason in a way that is consistent with one's knowledge. Developmental theories have, in contrast, tended to examine changes in the ability to generate inferences that correspond to logical norms, in a way that is relatively independent of empirical knowledge. Nonetheless, the interplay between logic and knowledge is critical to understanding how reasoning develops, and this is one of the major themes of the developmental theories that will be described.

There are, however, different mechanisms that could explain interactions between contextual knowledge and reasoning. On the one hand, it has been claimed that biology can account for at least some of the ways that people reason, since evolutionary mechanisms could create ways of thinking that are rational in the sense that they allow inferences and judgments that directly reflect important characteristics of evolved performance and social structures. Other explanations involve the development of specific cognitive processes that follow a developmental trajectory and results in developmental changes in reasoning abilities. We will examine different approaches to development of reasoning within this general distinction. We start by examining Piaget's theory, since this combines both biological and developmental perspectives, and it was the impetus for many subsequent developmental theories.

3.1 Piaget's Theory

Piaget's theory of cognitive development proposes that development occurs through the constant interaction between cognitive assimilation and accommodation, which are biological processes the use of which leads to a slow but progressive increase in the power of reasoning processes (Piaget, 1972). Without going into too much detail, one of the key factors characterizing the increasing ability to make logical inferences is the existence of three major levels of abstraction, with the transition being mediated by a process referred to as reflexive abstraction (Piaget, 2001). This is the ability to think about lower-level reasoning and represent the commonalities in more abstract form. The initial sensorimotor level uses action and perception-based schemas. A second level, concrete operations, uses an initial form of abstraction that is linked to the general characteristics of physical objects. The third level, formal operations, uses a higher level of abstraction that allows the manipulation of general concepts that are no longer tied to physical objects. Progression through each of these three general levels leads to an increasing ability to make inferences and judgments that, at least in theory, reflect the logical structure appropriate to a given level. The key to understanding this progression is the idea that at any given level, children are "locally rational." That is, they make inferences that are consistent with the structural information available at any given level. Thus, sensorimotor inferences are consistent with the structure of physical action schemas, and so on. It is not until the formal operational level that inferences become rational in a larger sense, since the structure of formal operational schemas functions at a very high level of abstraction. Interestingly, empirical examination of this model has led to two very different criticisms. On the one hand, there is research that suggests that even very young children are capable of being logical in a way that should only be accessible to formal operational adolescents and adults (Hawkins, Pea, Glick, & Scribner, 1984). On the other hand, as we have already seen, much research suggests that even educated adults are not consistently logical.

One theory that has attempted to account for the latter results within the Piagetian framework is Overton's competence performance model (Overton & Ricco, 2011). This theory makes a distinction between the theoretical competence to reason logically, which follows the basic trajectory described by Piaget, and use of this competence, which is subject to a variety of performance-related factors. Consistent with this approach, several studies have found that manipulations designed to improve reasoning have effects that are clearly age related (O'Brien & Overton, 1980, 1982).

However, other approaches have focused on empirical results that indicate that very young children can sometimes reason logically. These have sometimes been interpreted within a biological perspective.

3.2 Evolution and Reasoning

Natural-logic theory A very different approach is provided by Braine's natural-logic theory (Braine, 1978; see also chapter 3.2 by O'Brien, this handbook). This theory has an empirical basis in studies that show that under certain circumstances, and at least with a limited range of inferences, even quite young children are able to make logical deductions (e.g., Hawkins et al., 1984). There are two major components to the theory. The first is the idea that people have specific algorithmic inference rules embedded into the cognitive system. These rules are essentially syntactic in form, and they allow analysis of the syntax of a given inference in order to generate a conclusion that is theoretically independent of context. The second component is a biological underpinning. The basic argument is that in certain circumstances, it is absolutely critical for individual survival to be able to make very rapid and accurate inferences. Thus, biology equips people with selected inference rules that allow consistent production of logical inferences in situations where these inferences are critical. One such example is the modus ponens inference, which is a basic inference from conditional premises of the form “If *P* then *Q*; *P* is true” to “*Q* is true.”

Although this model of reasoning suggests that people are equipped with rules of inference that always give the logically correct response, existing empirical data show much more variability than would be suggested by the model. In order to account for such variability, the theory adds an interpretational module to the basic mechanisms underlying reasoning. This in turn creates an interaction between empirical knowledge, especially knowledge of the pragmatics of a given situation, and reasoning.

Cheater detection modules Another strong biological approach to reasoning was suggested by Cosmides (1989; see also chapter 10.6 by Cosmides & Tooby, this handbook). This theory had its origins in studies of the Wason selection task (Wason, 1968), which was a task first conceived as a way of showing that even very well-educated adults did not always make formally correct inferences. People were shown four cards, each of which had a number on one side and a letter on the other. A visible top of each card showed, respectively, a vowel, a consonant, an even number, and an odd number. Subjects were presented with a conditional rule of the form, “If a card has a vowel on one side, then it has an even number on the other.” They were asked to choose which cards they would turn over in order to either confirm or disconfirm the rule. The logically correct answer is, “The card with a vowel and the card with an odd number.” Both the original study, which was done with philosophy students, and several replications consistently found remarkably low levels of correct responding. Subsequent studies examined conditions under which the rate of correct responses was higher. One of the more intriguing results was that use of certain kinds of social rules led to very high levels of correct responding, for example, “If a person wants to drink at a bar, then they need to be over 21” (Cheng & Holyoak, 1985). With such a rule, people have no problems choosing cards that represent a person drinking and a person who is less than 21. In order to explain these results, Cosmides proposed that these social rules lead to good logical performance because they tap into a specific cheater detection module that has biological origins. The general proposition was based on the idea that social exchange and explicit or implicit contracts are a vital part of human social structure and have been so for a very long time. However, cheating is also a basic part of social interactions. Thus, it is argued that, in order to maintain a social structure based on exchange, people have developed a specific, specialized way of identifying cheaters. Consistent with this point of view, studies have shown that even very young children are able to produce logically correct inferences on some forms of the Wason selection task (Cummins, 1996; Girotto, Light, & Colbourn, 1988). Critically, such a module is biologically designed to allow people to interact in social situations in a way that maximizes the probability of successfully concluding a social contract but is not designed to reason logically. The fact that use of this module leads to the logically correct response in specific situations is thus basically incidental. In other words, this approach suggests that biology may have equipped people with inference mechanisms that are what we might call contextually rational. This means a kind of reasoning that accurately reflects the specific dimensions of a given social situation, which can be seen as rational, in the sense that it accurately reflects the specific parameters of the situation in question, but is not necessarily logical in a more formal sense.

Biologically based social reasoning It is interesting to examine some possible extensions of this notion of social reasoning, which shows the extent to which implicit inferences are affected by social schemas. One good example of this mechanism is given by attachment theory (Bowlby, 1969). The attachment system is biologically based and is designed to ensure the proximity of offspring to their principal caregiver during the period in which the offspring are most physically vulnerable. By itself, the system is a behavioral one that functions through an intricate mechanism of signals and internal emotions (Ainsworth, Blehar, Waters, & Wall, 1978). Depending on the reactions of the caregiver in situations of stress and/or anxiety, children create differing expectations, which results in very different forms of attachment behavior. For example, if a child’s caregiver is physically affectionate and comforting in situations of stress, they will have a secure attachment. If the caregiver is cold and distant, this will result in an avoidant form of attachment. Critically, this behavioral cycle is internalized in the form of an internal model of a child's attachment figure (Bretherton & Munholland, 2008). This internal model is then used to interpret the behavior of potential romantic partners (Hazan & Shaver, 1987). In other words, the internal model generates inferences about how important people in a person's life will react, which in turn reflects their early life experiences (Baldwin, 1992).

As we can see from these different approaches, biology has been claimed to underlie both a universal system of strictly logical deduction and specialized systems of contextual inferences that accurately mirror the constraints of specific social situations. These theories are designed to explain empirical data that show that certain types of inferences (which can be considered rational in the sense that they correspond to either logical or social norms) are consistently made by even very young children. However, there is also a very strong body of empirical evidence that shows important developmental changes in children's and adolescent reasoning. What we might call information-processing theories attempt to specify the underlying mechanisms that could explain these developmental patterns.

3.3 Information-Processing Approaches to the Development of Reasoning

As we have previously indicated, these approaches can be seen as the result of two tendencies. On the one hand, there is clear evidence that the efficiency of cognitive processing increases over time. On the other hand, it is also the case that people's knowledge about the empirical world increases concurrently. Both of these factors are conceivably linked to the development of reasoning abilities. The following theories put different weights on these factors.

Barrouillet's mental model theory One of the key factors to understanding the efficiency of cognitive processes is the capacity of working memory. This is a critical factor in the developmental approach to reasoning proposed by Barrouillet and colleagues (Barrouillet, Grosset, & Lecas, 2000; Barrouillet & Lecas, 1999; Gauffroy & Barrouillet, 2011). Their theory is based on mental model theory (Johnson-Laird & Byrne, 2002, which is a semantics-based approach to understanding reasoning (see chapter 2.3 by Johnson-Laird, this handbook). This attempts to model the processes that are used when people make deductions on the basis of a given set of major and minor premises. Since one of the principal forms of reasoning that have been examined by this theory, and other developmental theories, is conditional (if–then) reasoning, we will use this as an example.

Conditional reasoning examines the inferences that are made on the basis of a major premise of the form "If *P* then *Q*." There are four inference forms that characterize such reasoning, constructed by minor premises having true or false forms of the antecedent (*P*) or consequent (*Q*) terms. Two of these lead to logically necessary conclusions. These are modus ponens (MP), "If *P* then *Q*; *P* is true," which leads to the necessary conclusion "*Q* is true," and modus tollens (MT), "If *P* then *Q*; *Q* is false," which leads to the necessary conclusion "*P* is false." The other two forms have what can be referred to as invited conclusions, which are however not logically necessary. These are affirmation of the consequent (AC), "If *P* then *Q*; *Q* is true," which leads to the invited conclusion "*P* is true," and denial of the antecedent (DA), "If *P* then *Q*; *P* is false," which leads to the invited conclusion "*Q* is false." However, for both the AC and the DA inferences, the logically correct response is to deny the invited conclusions.

Mental model theory proposes that people have a theoretical representation of conditionals that include combinations of antecedent and consequent terms that correspond to the true rows of the logical truth-table representation. However, the actual process people use is complicated by the fact that constructing such internal representations requires cognitive resources. Thus, a two-stage process is proposed that allows maximal use of memory in particular. When reasoning with a conditional statement "If *P* then *Q*," people start with an initial representation (model) of the statement, which simply represents the conjunction of the antecedent and the consequent terms, in the following way:

P *Q*

for each of the four different inferences, then the model is scanned for cases involving the minor premise, particularly for cases in which the minor premise is associated with two different possible states. With this initial representation, people will make the MP inference and will accept the invited conclusion to the AC inference.

This initial representation can in some circumstances be fleshed out by the addition of other models that are also consistent with the conditional relation. The simplest of these leads to the following representation:

P Q
not-*P* not-*Q*

These models correspond to a biconditional interpretation, that is, "*P* is true if and only if *Q* is true." With this representation, people will make the correct inferences for the MP and the MT forms, and they will accept the invited conclusions for the AC and the DA forms. Such an interpretation corresponds to a pattern of inferences very frequently observed in children.

Finally, the full interpretation of conditionals requires the addition of a further model, leading to the following representation:

P	*Q*
not-*P*	*Q*
not-*P*	not-*Q*

With such a representation, people will make the correct inferences for the MP and the MT forms, and they will reject the invited conclusions for the AC and the DA forms. Mental model theory supposes that the interpretation given to conditional statements is a basically semantic process based on understanding of language, modulated by pragmatic considerations (Johnson-Laird & Byrne, 2001). In other words, people will generate models of full conditionals unless cognitive and/or contextual constraints limit their ability to do so.

Barrouillet's theory makes the very strong claim that working-memory constraints are the primary developmental factor determining how children and adults reason (Barrouillet & Lecas, 1999). The key explanatory factor is the idea that working-memory capacity constrains the number of models that people can actively manipulate. Young children have very limited working-memory capacity and are limited to a single model. This leads to a conjunctive interpretation of conditionals. Older children have increasing working-memory abilities and are able to manipulate two models, which leads to the generation of a biconditional interpretation. Finally, much older adolescents and adults have sufficient working-memory capacity to generate the three models required for the full interpretation of conditionals.

Empirical evidence for this model has used tasks that attempt to directly examine the interpretation that is made of conditional statements. One such task is the truth-table task, in which people are given conditional statements and are asked whether each of the four combinations composed of true or false antecedent and consequent terms makes the conditional true, false, or neither true nor false. Several studies have found a clear developmental progression from a conjunctive interpretation, which is predominant until 8 or 9 years of age, to a biconditional interpretation, predominant until 11 to 12 years of age, to a conditional interpretation, which appears in mid-adolescence, with an additional relationship to measures of working memory as hypothesized (Barrouillet & Lecas, 1999; although see Markovits, Brisson, & de Chantal, 2016).

This theory suggests that the ability to make logical inferences resides primarily in the increasing capacity of the cognitive system. Interestingly, it supposes that the underlying logic is determined by the way that statements are interpreted and that such interpretations are theoretically accessible even to young children. It should be noted that this theory does acknowledge the existence of interpretations reflecting contextual, pragmatic factors, which lead to inferences that are not logically adequate but pragmatically appropriate (Barrouillet, 2011). Nonetheless, it does incorporate one of the more controversial aspects of mental model theory, which is the idea that in ideal circumstances, reasoning will conform to the norms of standard logic. Thus, rationality in a larger sense can be seen as the result of a more adequate cognitive apparatus that can increasingly profit from the basic capacity for logical reasoning.

Semantic redescription theory Another approach that is based on mental model theory has been developed by Markovits and colleagues (Markovits, 2004; Markovits & Barrouillet, 2002). This theory postulates that the basic interpretation of conditionals is used as a retrieval cue for the activation of information present in semantic memory, which is then incorporated into a mental model. Two major classes of information have been shown to impact the way that people reason. The first of these are alternative antecedents. These are propositions *A* that differ from *P* and for which "If *A* then *Q*" is true. For example, consider the conditional rule "If a rock is thrown at a window, then the window will break," for which examples of alternative antecedents are "if a chair is thrown at a window," "if any hard object is thrown at a window," and so on. A great many empirical studies have shown that the tendency to accept or to reject the invited conclusions to the two invalid inferences (AC, DA) is directly related to the accessibility of alternative antecedents in memory (Cummins, 1995; Cummins, Lubart, Alksnis, & Rist, 1991; Markovits, Fleury, Quinn, & Venet, 1998; Markovits & Vachon, 1990; Thompson, 1995). Another form of information that is cued by conditional rules are disabling conditions (Cummins et al., 1991). These are conditions that allow *P* to be true without *Q* being true. For example, a disabling condition for the conditional rule presented above would be "The window is made of Plexiglas." Studies have shown that the tendency to accept the logical conclusions to the MP and MT inferences is related to the relative accessibility of disabling conditions in memory (Cummins, 1995; Cummins et al., 1991; De Neys, Schaeken, & d'Ydewalle, 2003). One of the first implications of this theory is that the ability to reason logically is associated with the efficiency of people's retrieval processes (Markovits & Quinn, 2002). However, the retrieval processes used during reasoning are not targeted but tend to result from activation of all the information that is associated with the premises (Janveau-Brennan & Markovits, 1999; Markovits & Potvin, 2001). Thus, the tendency to reject the AC and DA inferences is also associated with the tendency to reject the MP and MT inferences. This in turn suggests the importance of processes that are used to inhibit the retrieval of information that is inconsistent with the basic premises (Handley, Capon, Beveridge, Dennis, & Evans, 2004; Simoneau & Markovits, 2003). On a general level, this theory suggests that the ability to reason logically depends on the amount of information stored in semantic memory, the ability to retrieve this information, and the ability to inhibit retrieval of inappropriate information (i.e., information that contradicts the major premise). Since all of these factors increase developmentally, this results in a general improvement in the ability of children and adolescents to reason logically (Janveau-Brennan & Markovits, 1999).

However, this theory also postulates the existence of a redescriptive process as suggested by Karmiloff-Smith (1995), which produces descriptions of alternative antecedents of an increasingly abstract nature, resulting in a developmental increase in the ability to be logical with premises that are more abstract. Empirical studies that have examined the ability of children and adolescents to make consistently logical inferences have shown a clear age-related progression related to the content of the conditional rules, which in turn is related to the extent to which these rules allow accessibility of alternative antecedents and/or disabling conditions. These can be summarized by the following sequence:

- category-based conditional rules (if an animal is a dog, then it has legs),
- causal conditional rules (if a rock is thrown at a window, then the window will break),
- contrary-to-fact conditional rules (if a feather is thrown at a window, then the window will break), and
- abstract conditional rules (if XY, then it will blrp).

Studies have shown that children as young as seven or eight years of age are able to reason logically with category-based conditionals (Markovits, 2000; Markovits & Thompson, 2008). However, reasoning logically with causal conditionals is more difficult; it is not observed before 11 or 12 years of age (Janveau-Brennan & Markovits, 1999; Markovits, 2017). Reasoning with contrary-to-fact conditionals and with abstract conditionals is much more complex, with the former showing high rates of logical reasoning only at late adolescence (Markovits, 2014; Markovits & Vachon, 1989), while abstract reasoning is not found at a high rate even with educated adults (Markovits & Lortie-Forgues, 2011; Markovits & Vachon, 1990). The redescriptive theory assumes that people think about the kinds of reasoning that they can do well and can use this to construct a more abstract representation of the processes involved, which then allows a higher level of reasoning.

This further supposes that the four categories of premise described previously correspond to two major levels of abstraction. The first two, comprising reasoning with category-based and causal premises, require retrieval of information that is directly or indirectly available in semantic memory. The second two, reasoning with contrary-to-fact and abstract premises, require the active construction of relevant information. Evidence for this comes from studies that have shown that it is possible to improve reasoning by asking reasoners to simply generate explicit alternatives for premises that are at a higher level of abstraction than those used for reasoning (Markovits, 2014; Markovits & Lortie-Forgues, 2011), while generating alternatives for highly familiar premises has no effect. In addition, these studies have found clear suppression effects showing that levels of logical reasoning with concrete and familiar premises are lowered when reasoners are first asked to reason with abstract premises (Markovits & Vachon, 1990).

3.4 Divergent Thinking and Reasoning

This theory also suggests an interesting relationship between logical reasoning and creativity. One of the more important factors that allow people to make logical inferences based on conditional rules is the ability to maintain the conditional in memory and at the same time to activate alternative antecedents. This process is made more difficult when premises contain terms that are already strongly associated (Quinn & Markovits, 1998), so that overall rates of logical reasoning are related to the ability of reasoners to retrieve information that is outside the usual range suggested by the premises (Markovits et al., 1998; Markovits & Quinn, 2002). This ability is very similar to that involved in divergent thinking, which is a key component of creativity (McCrae, 1987). There is in fact some evidence that differences in divergent thinking drive the very early ability of children to reason logically (de Chantal, Gagnon-St-Pierre, & Markovits, 2020; de Chantal & Markovits, 2017; Markovits & Brunet, 2012). For example, very young children have great difficulty in accepting the uncertainty of even a very simple category-based inference, such as "If an animal is a dog, then it has four legs. An animal has four legs. Is it a dog?" However, if they are asked to do a divergent-thinking task (without examples) such as "We can make noise with many things. I'd like to know some ways of making noise," their ability to accept uncertainty increases greatly. The general idea that rationality in a broader sense depends upon the growing ability of reasoners to envisage possibilities (which is important for divergent thinking) and then to account for these possibilities when making inferences, is very similar to the interplay between possibility and necessity that was identified by Piaget in his later works (Gauffroy & Barrouillet, 2011; Piaget, 1987).

4. Conclusion

While there is no real consensus about the way that rationality develops, the variety of approaches does suggest a multidimensional trajectory that might usefully be extrapolated from these theories and the associated empirical data. One of the themes is the interaction between context-dependent forms of reasoning and more general forms of reasoning, of which the strongest version is metacognitive and abstract. The simplest version of this would suggest that the earliest form of rational thinking is contextual, either due to biological underpinnings or early experience, with rationality implying reasoning that reflects specific situational constraints. Subsequent development would involve a gradual replacement of this form of reasoning with more abstract and general forms.

However, one interpretation of the many studies that have examined the development of reasoning is that inferences and judgments can be seen as interactions between some form of rationality and a growing understanding of the structure of the empirical world, with the latter anchored in a biological substrate. Actual inferences can then be seen as the product of an ongoing exchange between children's logical abilities and their increasing understanding of the empirical world. Each of these components is subject to developmental variation underpinned by clear increases in the computational power of the cognitive system. Thus, development allows children to become both more logical and more conversant with the way that the empirical and social worlds are constructed. The paradox of development is that real-world knowledge is necessary for the construction of an increasingly powerful ability to make rational judgments, and it is at the same time a driver of judgments that reflect the often irrational structure of the social and possibly the physical world (Artman, Cahan, & Avni-Babad, 2006). Accounting for this complex interaction is one of the major challenges of understanding the development of rational thought.

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