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Introduction: Why is understanding the development of reasoning important?

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This special issue of *Thinking & Reasoning* focuses on the development of reasoning, with contributions from several distinguished developmental researchers. Although there is a long tradition of developmental work on reasoning, there has been a marked decrease in such studies recently. Both this fact and the reasons for it constitute the rationale for this special issue. Much of the initial impetus for research about reasoning was motivated by Piaget's theory of formal operations (Inhelder & Piaget, 1958). Piaget considered that an understanding of the formal rules of inference was the epistemological basis for the kind of hypothetico-deductive mode of thinking that appears in adolescence. This led to an explosion of research focused on two (somewhat mistaken) predictions that were made from this theory, which have generally led to the present decline of both Piagetian theory and developmental research on reasoning. The first was the prediction that young children who do not possess the basic competence for formal operations (or in some cases, such as conservation and transitivity, concrete operations) will be unable to give the right answer to any problem that can be identified as concrete or formal operational. A series of studies in a variety of domains (Bryant & Trabasso, 1971; Dias & Harris, 1988; Hawkins, Pea, Glick, & Scribner, 1984) showed that very young children can respond "correctly" to many such problems. In fact, this basic analysis has been extended to babies (e.g., Baillargeon & DeVos, 1991) and other species such as pigeons (Von Fersen, Wynne, Delius, & Staddon, 1991). This led to claims that very young children are "logical" and that the basic competencies that Piaget identified as taking many years to develop

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appear to be present very early, if they are not essentially innate, something that is clearly suggested by studies with babies and pigeons. The basic conclusion of these studies is that the most interesting problems in psychology consist of documenting the nature and basis of early competence. Development is seen as uninteresting, since it essentially involves problems of implementation or detailing performance factors that make this more or less difficult.

The second general prediction that was made from Piaget's theory led researchers in a completely different direction. This was that formal operational competence must inevitably develop and that any educated adult should be capable of giving the correct answer to any and all problems that can be identified as formal operational. This led to studies which clearly showed that, in many cases, adult reasoners do not give the logically appropriate response to a variety of reasoning problems (e.g., Wason, 1968). This in turn prompted a general claim that formal operational competence is not a useful concept since few reasoners appear to have it in a consistent way. This line of research has also led to a decline in development work, since there is no point in looking at the development of something that is not present.

Thus, on the one hand, many researchers claim that logical competence (as defined by Piaget's theory) is innate or close to it, while, on the other hand, other researchers claim that logical competence (as defined by Piaget's theory) is not present even in adults. As a result of these two wildly divergent conclusions, and therefore for very contradictory reasons, research whose aim is to trace the development of reasoning has become relatively rare. One of the most direct consequences of this is that many theories have little or no explicit developmental components, leaving the question of what, if anything, happens between birth and adulthood essentially unanswered. Another consequence is the clear fragmentation that exists between studies that look at children's reasoning and those that look at adult reasoning. This has allowed researchers who study children and those who study adults to make claims that may well be in direct or implicit contradiction to existing empirical evidence. For example, some researchers (Hawkins et al., 1984; Leevers & Harris, 1999) have claimed that very young children are able to reason logically with abstract or false premises. However, claims of early competence must also explain why this kind of reasoning is difficult even for educated adults (e.g., George, 1997), something that is simply ignored. Another example is that of Johnson-Laird's mental model theory. While paying relatively little attention to development, the theory's claim that the major constraint in reasoning is working memory capacity allows some clear predictions about younger children. Specifically, children should invariably show conditional reasoning patterns corresponding to an interpretation of the conditional that is either "and" or the biconditional (Johnson-Laird &

Byrne, 2002). However, research on children's reasoning has shown that this is simply not true (e.g., Kuhn, 1977; Markovits, Venet, Janveau-Brennan, Malfait, Pion, & Vadeboncoeur, 1996; Rumain, Connell, & Braine, 1983). In both cases, these theories are able to make unconvincing claims since the relatively hermetic nature of research on children and that on adults allows researchers to ignore a large quantity of empirical data.

If we leave aside, for the moment, the question of interpretation, the two research programmes that we have spoken of can be summarised by two sets of results. One set comprises studies which have found that young children can reliably produce "correct" answers to some reasoning problems. The other set comprises studies which have found that adults do not reliably produce "correct" answers to other reasoning problems. Now, there is no reason to doubt either of these sets of results in themselves. The real question is just how to interpret them. At least one of the reasons that researchers looking at children's competence and those looking at adults' incompetence can arrive at what appear to be completely contradictory conclusions in what is nominally the same discipline, is that they rarely interact. This lack of interaction allows use of the same terms to describe what appear to be very different measures, and allows theories to simply ignore data that contradict some basic premises. We would argue that the clearest form of interaction is the developmental study, since (1) it presupposes some degree of continuity between children and adults, (2) it requires the use of compatible measures of a given concept across ages, and (3) it explicitly requires theoretical models to make clear predictions about the extreme points of development and the underlying mechanisms that explain change or lack of it.

The papers in this special issue of *Thinking & Reasoning* illustrate this point by examining development in three major contexts. The first relies on the basic idea that some critical changes during development are due to changes in reasoners' information processing capacities. Thus, Halford and Andrews present their model of relational complexity and attempt to model how this basic processing capacity could determine developmental patterns across several domains. The second context examines development in the light of current dual-process theories. These theories postulate the existence of two distinct systems of reasoning, one being associative and immediate, if not unconscious, and the other being rule-governed and effortful. While such theories provide the potential for interpreting at least some of the observed variability in reasoning as being due to the interplay between the two systems, they remain, at least for the moment, focused only on adult reasoning. They thus leave unanswered the same key questions as other current theories of reasoning, and a developmental approach, as suggested by papers from Klaczynski and Cottrell, or Handley, Capon, Beveridge, Denis, and Evans in this issue, is equally critical to understanding the nature of these theories. Finally, the third context postulates that at least some of the important differences observed in children's and adults' reasoning can be accounted for by metacognitive understanding and control. Papers by Kuhn, Katz, and Dean, and Moshman in this issue claim that one of the key developmental differences between children and adults, and often between reasoners of the same age but of differing ability, is the capacity to reflect on one's own reasoning, and to use the product of this reflection to organise complex reasoning processes.

INFORMATION PROCESSING CONSTRAINTS ON DEVELOPMENT

Information processing theories usually account for cognitive development by assuming that there is an age-related increase in computational power, which is often conceived of as an increase in cognitive, or working memory, capacity (Pascual-Leone, 1970; Case, 1985, 1992). Both the increase of this basic processing capacity and the increase of the knowledge base through learning would allow children to solve increasingly complex reasoning problems with age. Complexity is a function of the number of processing steps and the quantity of representations to be constructed, maintained, and manipulated. This kind of approach does not deny that young children might be able to perform optimally, even from a normative point of view, when the problems are simple and do not exceed their limited capacities or when relevant knowledge is readily available from long-term memory. The hypothesis of computational limitations can be used to account for the discrepancies observed in adults between actual responses and normative models. These would arise from performance errors in particularly demanding tasks with unfamiliar and decontextualised contents. We have recently put forward such a developmental theory for conditional reasoning by mental models, in which reasoning is constrained by both a limitation in working memory capacities and the efficiency of the retrieval process (Markovits & Barrouillet, 2002). Basically, the development of conditional reasoning would result from an increasing capacity with age to construct, maintain, and process a larger number of mental models in working memory. In the present special issue, Handley et al. provide evidence that working memory capacity in children is a good predictor of logical reasoning performance in conditional and relational problems when they involve belief neutral and knowledge-free contents (see also Barrouillet & Lecas, 1999, for similar findings in children, and Markovits & Doyon, in press, with adults).

In their Relational Complexity (RC) theory, Halford, Wilson, and Phillips (1998) go further by assuming that the complexity of reasoning is not a function of the total information to be processed in the task, but the number of independent variables that can be related in a single cognitive representation. Thus the difficulty of a given form of reasoning would depend on the relational complexity of the mental model required to represent the concept it involves. Because relations with more arguments have a higher computational cost, the complexity of relations and children's increasing processing capacity interact to determine developmental patterns of reasoning. In this special issue, Halford and Andrews suggest that children's reasoning can no longer be assessed by reference to the norms of logical inference, but by the complexity of the mental model needed to solve a specific task. For example, they argue convincingly that young children's success in making transitive inferences on the task used by Pears and Bryant (1990) is due to the specific requirements of this task, which can be solved with binary relational representations; whereas more traditional transitive inferences are ternary relational and thus appear later in development (after 5 years of age). In the same way, the complexity analysis applied to categorical syllogisms makes it clear that the most difficult of these problems involve a five-dimension representation, and thus are often failed even by adults who can only process quaternary relations. The authors conclude from their investigation of a large range of deductive reasoning domains that, though there are some experimental results indicating that children can occasionally perform well on tasks which seem to perplex adults (Klaczynski & Cottrell, this issue), the inferences of younger children are invariably less complex than those of older children.

The information processing approach is a valuable tool in modelling some basic developmental trends. It is less clear that this approach can, by itself, successfully account for variability in adult performance. It has been argued that the computational limitations hypothesis cannot totally explain the gap that exists between adult performance and the norms prescribed by formal logic (Stanovich & West, 2000). It has thus been assumed that some responses are not underpinned by an analytic and logically driven system of thought but by a more conversational and social system which is more associative and heuristic than rule-based. Thus, two reasoning systems, both being rational in some way, could coexist. The developmental implications of this dual process approach have not been worked out, but this theoretical framework could provide a fruitful avenue of research.

DUAL PROCESS ACCOUNTS

This contrast between two coexisting and distinct systems of reasoning has been described either as heuristic vs analytic (Evans, 1989), associative vs rule-based (Sloman, 1996), or tacit vs explicit (Evans & Over, 1996). These oppositions seem to refer to the more general one posited by Reber (1993) between implicit and explicit cognition. The first system, referred to as

System 1 by Stanovich and West (2000), encompasses automatic, largely unconscious, and undemanding processes that are part of an interactional intelligence involved in highly contextualised, socialised, and personalised situations. By contrast, the second system, System 2, encompasses controlled and demanding processes involved in analytic and logical intelligence required to deal with decontextualised situations. Because System 1 processes are automatic and largely unconscious, System 1 is primary, and the tendency to code specific features of problem content and to retrieve semantically associated information would constitute a fundamental computational bias. Thus, Stanovich and West (2000) suggest considering the logically driven System 2 as an override system for some of the automatic and obligatory computational results provided by System 1. The interplay between the two systems thus accounts for both young children's competence, which often occurs in highly contextualised and socialised problems where both systems cue the same response (Harris & Nunez, 1996), and adults' incompetence, which is mainly observed when the two systems cue different responses, as in the problems often used in the heuristic and biases literature.

At a first glance, dual process theories leave little room for development. Indeed, the processes involved in implicit cognition (System 1) are known to be largely independent of developmental or individual differences (Reber, 1993; Saffran, Aslin, & Newport, 1996; Vinter & Detable, 2003; Vinter & Perruchet, 2000). However, development could occur because the capacity to inhibit System 1 when System 2 and decontextualised reasoning is needed could increase with age. For example, Braine and O'Brien (1991) suggested that the development of the understanding of conditional sentences would be based on an increasing age-related capacity to set aside the pragmatic principles in situations that require logical treatment (e.g., laboratory tasks). In the present issue, Handley et al. provide evidence that the executive ability to inhibit heuristically cued responses based on prior beliefs plays a key role in the children's ability to decontextualise their reasoning (see also Simoneau & Markovits, 2003). In their contribution on children's understanding of sunk cost, Klaczynski and Cottrell suggest a slightly different hypothesis. The increased tendency of adolescents to set aside heuristics and make normative decisions could result from their greater willingness to engage in what they call "metacognitive intercession". The process of overriding implicit heuristic cognition is conscious and thus likely requires metacognitive abilities that develop with age. Interestingly, Klaczynski and Cottrell envision two other sources of development. First, inhibitory capacities and metacognitive abilities are not sufficient without the dispositional tendencies to use these capacities and abilities. Disposition against premature closure, cognitive confidence, or reflectivity are factors that could develop with age and account for at least a part of developmental differences in the same way they account for individual differences in using System 2 reasoning (Stanovich & West, 1997, 1998). Second, Klaczynski and Cottrell note that adults possess more analytic competence than children—something that is clear from information processing studies—but also more experiential knowledge and heuristics that are probably easier to activate with age. This last developmental trend, though usually overlooked, could be of particular interest if we suppose that the two systems of reasoning are optimised for different situations (contextualised or abstract) and different goals.

We have seen that metacognition plays, according to Klaczynski and Cottrell, a major role in the interplay between experiential and analytic processes. Many authors have suggested that metacognitive processes are in fact central to understanding the nature of cognitive development and the development of rational thought.

METALOGICAL DEVELOPMENT

Metacognition refers both to the ability to think about thinking, and to explicitly control the organisation of one's reasoning processes. The study of the development of metacognitive abilities has a long history. Metacognition as executive control has often been used to explain some basic competence–performance distinctions, specifically the all-too-common cases of children and adults who are able to solve problems in one context, but appear to be unable to do so in a different context. It also has been used as a label for the ability to create abstract concepts that are derived, not simply from empirical knowledge, but from some process of reflection upon the way that we think. As both Kuhn and Moshman argue in their respective contributions to this special issue, we need both constructs in order to understand the complex nature of what truly develops in reasoning. This is particularly relevant when early competence is examined. Most theories that make this claim look at fairly simple forms of reasoning. One important example is Braine's natural logic theory (Braine, 1978), which claims that there are some forms of reasoning that are essentially innate. These are quite straightforward forms of reasoning, such as the principle of modus ponens, which states that "If P then Q, P is true, then Q must be true". In fact, very young children consistently make this inference on a variety of premises. However, when more complex contexts are used, there is a clear developmental trend to fail to make the same inference (Simoneau & Markovits, 2003). There is no reason to believe that older adolescents and adults lose the ability to make the simple modus ponens inference. How then to explain the difference? Both Moshman and Kuhn et al. convincingly argue that the addition of more complex forms of information requires more complex forms of understanding and control. They claim that developmental complexity in reasoning is not additive, since it is not simply an accumulation of simple reasoning principles, but that coordinating and understanding complex forms of reasoning implies the development of meta-concepts and corresponding forms of executive control. When young children's performance on complex tasks requiring argumentation and understanding of basic logical metaconcepts is compared to that of adults, the developmental difference between them becomes very clear. As Kuhn et al. also argue, the same difference can be found when comparing "good" and "bad" reasoners of the same age. These two papers convincing argue that one of the key problems with most contemporary accounts of reasoning is a failure to provide for explicit higher-level procedures and concepts, a failure that is compounded by selective blindness as to the nature of developmental change.

This special issue thus offers a varied and almost exhaustive overview of the different ways to fill the theoretical and empirical gaps between studies of children's reasoning and studies of adult reasoning and to solve the apparent contradiction between young children's competence and adults' "incompetence". We hope that it will constitute a step towards a renewal of the tradition of the developmental study of reasoning, which remains an important and privileged means for understanding human cognition.

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