Opinion

Dual–systems and the development of reasoning: competence–procedural systems

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Dual-system, dual-process, accounts of adult cognitive processing are examined in the context of a self-organizing relational developmental systems approaches to cognitive growth. Contemporary adult dual-process accounts describe a linear architecture of mind entailing two split-off, but interacting systems; a domain general, content-free 'analytic' system (system 2) and a domain specific highly contextualized 'heuristic' system (system 1). In the developmental literature on deductive reasoning, a similar distinction has been made between a domain general competence (reflective, algorithmic) system and a domain specific procedural system. In contrast to the linear accounts offered by empiricist, nativist, and/or evolutionary explanations, the dual competence–procedural developmental perspective argues that the mature systems emerge through developmental transformations as differentiations and intercoordinations of an early relatively undifferentiated action matrix. This development, whose microscopic mechanism is action-in-the-world, is characterized as being embodied, nonlinear, and epigenetic. *WIREs Cogn Sci* 2010 DOI: 10.1002/wcs.120

INTRODUCTION

If people are conceptualized as relational self-organizing and self-regulating developmental systems, then a fundamental feature of cognitive development across the life span is that it entails system differentiation and inter-coordination.[1] Just as the biological system develops a central and a peripheral nervous system, each assuming different but coordinated functions, it is reasonable to expect that the cognitive system develops inter-coordinated central and peripheral knowledge processing systems. Although formulated in the paradigmatic context of a linear 'architecture of mind' rather than a non-linear 'relational developmental systems 'paradigm of mind',[2,1] cognitive science has increasingly embraced a similar insight in its proposals for 'dual systems' 'dual-process', accounts of adult reasoning, judgment, and decision making.[3] Dual-process accounts postulate the operation of a central, domain general system (often termed 'system 2'), characterized as 'analytic' and relatively content free in nature, and a peripheral, domain specific system (often termed system 1), which is more 'heuristic', modular and highly context dependent.

Dual-process theories, focusing primarily on individual differences in adult cognition, are paralleled in the field of life span cognitive development by a dual-process account of the ontogenesis of deductive reasoning. After some terminological modifications (originally termed 'Competence-Utilization/Acquisition'),[4] this ontogenetic perspective has come to be termed a 'competence (system 2)–procedural (system 1)' developmental systems approach.[5,6] Historically, the dual adult and the dual ontogenetic models emerged from virtually identical roots. Although various dual-processing (and multi-processing) accounts have a long history in psychology,[7,8,4] contemporary theories began to emerge in the 1970s and 1980s.

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ORIGINS OF DUAL-SYSTEM MODELS

Dual-processing became, in large measure, a reaction to problems associated with accounts based on the notion that the mind operates in an exclusively domain specific fashion. However, this exclusivity of domain specific accounts—which in the 1980s explicitly became the 'massive modularity' hypothesis—itself had represented a turning away from earlier domain general accounts found in theories such as those of Piaget[9] and Werner.[10] The competence–procedural developmental systems approach began to be formulated in the early 1970s in the context of the same domain general issues. That is, at that time, criticisms arose—based on findings of both inter- and intra-individual variability in task performance—concerning Piaget's claims of universal (domain general) reasoning processes. In a now classic paper, Flavell and Wohwill[11] borrowed from Chomsky the concept of a 'competence–performance' distinction to argue that while reasoning necessarily entails a competence system (i.e., broad, rule governed, content-free reasoning system), the processing of this system may be supported, facilitated, or overridden by various contextual factors. Frankish and Evans[7] similarly note that adult dual-process models arose from a recognition that 'logical processes seemed to compete with nonlogical biases (Ref 7, p. 13)' in determining performance. Thus, contemporary adult and developmental dual-system accounts arose from the single recognition that both domain general and domain specific system components are necessary for any inclusive explanation of cognitive processing.

THE DEVELOPMENTAL DUAL-SYSTEM, COMPETENCE-PROCEDURAL MODEL

The developmental dual-system competence-procedure version of the competence–performance distinction began to be formulated in the 1970s by Overton and colleagues in studies of class & spatial reasoning during early and middle childhood.[12–15] These studies demonstrated how perceptual processes may sometimes override and sometimes support reasoning performance. The model was extended to the area of deductive reasoning in childhood, adolescence, and adulthood beginning with a series of studies by O'Brien and Overton,[16,17] illustrating the relation between the availability of a well integrated abstract logical competence system, and the linguistic interpretation of propositions testing the truth status of conditional statements. The model has since been elaborated by Overton and colleagues (see Refs 5, 6, 18 for summaries) assessing developmental changes in competence–procedural systems using various deductive reasoning tasks and contexts. This account has offered an integrated approach in contrast to others that have argued either for the exclusivity of competence or mental logic systems explanations,[19–22] or for the exclusivity of procedural system explanations of logical reasoning (e.g., pragmatic schemas approach of Cheng and Holyoak[23,24]; mental models approaches of Johnson-Laird[25] and Markovits and Barrouillet[26]; metacognitive approaches of Kuhn and Franklin[27] and Moshman[28]). The competence–procedural model has also offered a principled relational developmental systems explanation for the ontogenetic acquisition of these systems, and in this it stands in contrast to both competence and procedural theorists who assume various empiricist, navitist, and/or evolutionary[23,24,29,30,21] modular models of acquisition.

The Competence (Algorithmic, Reflective) System 2

The competence system (system 2) is characterized by being a normative, abstract, idealized, dynamic model of the operations of mind that are relatively enduring, universal, and applicable to a broad range of phenomena. It is an idealization of the dynamic organization of these universal capabilities. As such, the competence system describes general performance specifications, but it is neutral on how the system is to be accessed or implemented.[31] As a dynamic organization it is, in and of itself, content free and is not to be considered as the 'mental representations' the adult mind uses when reasoning.[32] Highly contextualized representations are fundamentally products of procedural processing (system 1), although the decoupling of representations from real world actions is likely dependent on competence processing. The competence system is differentiated into two subsystems—an algorithmic and a reflective system—somewhat along the lines suggested by Stanovich.[33] The organization of the algorithmic subsystem is described—with respect to deductive reasoning—as a system of rules that mirror forms of logical arguments. The reflective subsystem entails processes of synthesis-analysis, abduction, and judgment. This subsystem corresponds generally to *metacognitive* reasoning skills. Klaczynski suggests a further distinction in the reflective subsystem between these skills a) as they involve the ability to reflect 'on how one knows, evaluate the accuracy of one's knowledge, monitor reasoning for consistency and quality, and plan/selects situationally appropriate strategies (Ref 34, p. 269)', and b) metacognitive *dispositions* that are motivational in character and entail beliefs about the value of engaging in effortful analysis. The competence subsystems as components of the larger system(s) process in a circular causal mode, as the solution of any abstract reasoning problem necessarily requires coacting reflective metacognitive skills and dispositions[34,27,28] as well as algorithmic content-independent inference rules.[35,6]

The Procedural System 1

The procedural system (system 1) is highly context dependent, and the context includes both the competence system and informational inputs. A procedure is an action means to an end or goal. It is generally efficient, relatively automatic, fast, and preconscious, in contrast to the flexible, effortful, slow, and relatively conscious nature of competence processing.[3] The specific character of procedures that can be used to account for the processing of problems are limited only by functional criteria—real-time processing and sensitivity to inputs, outputs, and internal states. Thus, for example, a deductive reasoning problem might be processed by actually thinking in terms of truth tables, by actually thinking in terms of Venn diagrams, by actually thinking in terms of natural deductive procedures, by mental models, by pragmatic methods, or by various methods employing direct experience. Further, procedural processing may reflect individual differences or individual strategies. As a consequence, different people may—at different times and under different circumstances—use different procedural processes in efforts directed at solving reasoning problems.

Co-acting Competence – Procedural Systems

The competence system functions to promote understanding (analytic function) while the procedural system functions to assure success (heuristic function). Understanding entails both the discovery of, and reflection upon, coherent patterns found in representations decoupled from procedural processing. The procedural system is composed of representations and individuated real-time action processes that may be sequentially ordered but are not enduring in the way that the competence system endures. For any given reasoning problem the engagement of both systems is necessary. To paraphrase Kant's effort at a rapprochement between rationalists and empiricist, logic (competence) without content (procedures) is empty; content without logic is blind. In fact, Kant's proposed structure of the adult mind is quite similar to contemporary dual-system accounts. Thus, Kant's 'forms of intuition' (procedural, system 1), which were understood to interact directly with the sensible world, provide input for the 'categories of understanding' (competence, system 2, algorithmic subsystem) and other active 'faculties' of mind (i.e., imagination, judgment, reason) (competence, system 2, reflective subsystem) yielding an object world that evidences both necessity and universality (i.e., valid knowledge). What both Kant's and contemporary dual-processing accounts lack is an explicit recognition that the proposed parts of mind are not split-off component features, but the highly complex and relationally integrated outcome of a self-organizing and self-regulating developmental process.[1]

As a dynamic relational mind, both competence and procedural processing are necessary in any reasoning situation. However, in any given situation, the degree of engagement of each system is itself situationally determined. In some contexts, the procedural system may operate *virtually* independent of the competence system.[33] For example, in everyday pragmatic situations, procedural processing is probably the default. In some reasoning contexts, procedural processing may support or facilitate competence processing. And, in some reasoning contexts, procedural processing may override competence processing. An override of the algorithmic competence, subsystem is illustrated within a deductive reasoning paradigm by the so-called 'belief-bias effect'. This effect refers to a tendency to accept or reject the conclusion of an argument on the basis of the *believability of the premises and/or conclusion* (procedural processing), rather than the *logical form of the argument* (competence processing). Thus, for example, it is sometimes the case that the following argument is judged as valid, when, in fact, it is not: 1, 'All living things need water'; 2, 'Roses need water'; 3, 'Therefore, Roses are living things'. That the faulty reasoning is an override of the algorithmic competence system is suggested by the developmental evidence that when task instructions stress the importance of a logical or formal evaluation of the argument, susceptibility to belief bias decreases across later childhood and adolescence,[36] though it is substantially present even in adults.[37]

Although not conceptualized in these terms at the time, it was procedural overrides of competence processing that led to the original competence–performance distinction. And it was this overriding that led a number of investigators to argue that a domain general logical processing system is an unnecessary feature of logical thought.[14,23,26,29,30,38] However, dual-processing theorists have demonstrated that an exclusive reliance on procedural processing may account for individual differences in reasoning, but it cannot account for extensive evidence of content-free logical reasoning.[6,18,35] This issue, however, still frames much of the developmental literature on deductive reasoning.

There is also good reason to believe that the reflective competence subsystem can override the algorithmic. The clearest case of this is in those instances where the logical form of an argument is ignored in a playful or imaginative fashion as in the 'invalid' argument: 1, 'Men die'; 2, 'Grass dies'; 3, 'Therefore, men are grass'. Another type of reflective override is evident in Wittgenstein's argument that the 'law of the excluded middle' is merely a part of one of many possible language games (Ref 39, paragraph 352). Given the fact that the reflective subsystem entails broad and deeply held epistemic dispositions, it is not surprising that deeply held beliefs might override logical thought. Such overrides do, however, complicate the picture concerning when phenomena such as belief bias are best attributed to procedural or competence processing.

DEVELOPMENT: THE RELATIONAL DEVELOPMENTAL SYSTEM

In contrast to empiricist, nativist, and evolutionary linear accounts of the origins of cognitive processing, the dual competence–procedural developmental approach argues that the mature systems represent the outcome of a dynamic ontogenetic process that is self-organizing and self-regulating. From this relational developmental systems perspective ontogenesis is embodied, nonlinear, and epigenetic. At the microscopic level, the mechanism of all developmental change is *embodied action-in-the-world*.[1,40] As with any self-organizing system, the person's embodied actions in the world lead, through complex positive and negative feedback loops, to greater complexity representing epigenetic differentiations and reintegrations or intercoordinations of processing systems. The procedural system differentiates to face outwards toward the world of sensible objects and further differentiates into multiple modular systems. Thus, following Stanovich[33] there appear to be a multiplicity of procedural systems; most of these are domain specific, but some may have significant domain general features (e.g., some encoding processes). Further growth of procedural systems proceeds primarily in terms of speed and efficiency of processing.

Development of Competence (Algorithmic, Reflective) System 2

The competence system differentiates inwards to the domain general world of reflection and forms. In contrast to the procedural systems, the competence system (algorithmic and reflective) undergoes emergent transformational changes as well as differentiations. While there may be questions concerning specific details, Inhelder and Piaget's,[41,42] and most importantly, the later Piaget and Garcia's[43] developmental theory of reasoning still serves quite adequately as an account of the development of the algorithmic competence subsystem. This self-organizing system begins as a complex organization of actions, and through embodied action-in-the-world moves to increasingly higher levels of organized (i.e., nonadditive) complexity. In early infancy, the system entails only coordinated overt actions. With development coordinated actions become transformed and incorporated into a level of complexity that can be modeled by a set of rules of coordinated action—a logic of action. For example, the infant pulling on a string to retrieve a toy represents, at an action level, the analog to the later propositional *modus ponens* argument (i.e., 1, If (P) pull on string, then (Q) get toy; 2, (P) Pull on string; 3, Therefore, (Q) get toy). With further development in childhood the logic of action becomes transformed and incorporated into a broader system that is internal and symbolic in character and entails rules most adequately modeled by class logic. The class logic rules, in turn, by late adolescence, become transformed and incorporated into a yet broader system of rules modeled as a natural deductive system featuring inference rules.[43,44] In a sense, the adult algorithmic competence is a layered system. However, the earliest logic of action along with the sensori-motor abilities developed during the early period may best be thought of as the base from which both the broad competence and procedural systems differentiated.

The development of reflected competence parallels and mirrors that of algorithmic competence. In this case, the developmentally embodied differentiations and reintegrations move toward increasingly complex and abstract higher orders of reflection. Beginning in infancy, where a primitive form emerges in the coordination of action, this system progresses at around 18–24 months to a level entailing symbolization processes, and the consequent *emergence* of language (i.e., a system of symbols) and thinking (i.e., symbol creation and symbol manipulation), thus establishing a first order of self-conscious reflection. From this base level of first order symbolic reflection, higher orders of reflection emerge during childhood and adolescence. Thus, in adulthood, second, third, and even higher order judgments are possible. In this, as in algorithmic development, the earlier forms are not lost but become incorporated into later forms.

Development of Procedural System 2

With respect to the retention of lower levels of processing within higher levels, it is important to emphasize that the procedural processing shows little structural change following the initial developmental differentiation of the procedural–competence system. As mentioned earlier, later developments of the procedural system primarily consist of increasing speed and efficiency of processing. As a consequence, the procedural system may be thought of as an early established, highly efficient, but not flexible system, which operates in the context of later established, increasingly more flexible, systems. In a recent paper, Apperly and Butterfill[45] review a large body of developmental evidence from the areas of number cognition and belief reasoning to argue for a dual-system model that reflects a similar developmental feature. In Apperly and Butterfill's model, early achievements in number cognition and belief reasoning are accounted for by an early emerging cognitively efficient, but inflexible, system (i.e., procedural, system 1), while later developmental achievements are accounted for by a cognitively flexible system (i.e., competence, system 2). Thus, for example, Apperly and Butterfill demonstrate that the apparent success of infants on recent nonverbal variations 'false belief' tasks requires skills associated with the developmental early efficient system, while demonstrating a fully elaborated 'theory of mind' entails skills associated with the cognitively flexible system. On the relation between these systems, Apperly and Butterfill's central claim is that early and late developing systems make different and complementary trade-offs between efficiency and flexibility. And this is also a central claim made in this article concerning early developing procedural systems, and later developing competence systems. Depending on contextual factors, each system may support, facilitate, or override the other.

CONCLUSION

In conclusion, recent analyses of dual-process approaches to cognition have raised the issue of whether the various finer distinctions being made across systems (e.g., algorithmic, reflective, dispositional) and between systems (e.g., domain general features of the procedural and, perhaps, domain specific features of competence) have begun to limit the usefulness of dual-processing accounts.[33,46] This could, perhaps, be argued on the ground of parsimony, and the need for precise clear-cut distinctions. On the other hand, from a relational developmental systems perspective, advances in complexity are the scientific expectation, and findings of rich layering and reciprocal interactions the rule. The dual competence–procedure developmental systems account strengthens contemporary adult dual-processing accounts by introducing a dimension of developmental levels of processing; a dimension that emerges from the activity of the developmental system itself.

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