Commentary: new kids on the connectionist modeling block

David Klahr

Department of Psychology, Carnegie Mellon University, USA

If we can construct an information-processing system with rules of behavior that lead it to behave like the dynamic system we are trying to describe, then this system is a theory of the child at one stage of the development. Having described a particular stage by a program, we would then face the task of discovering what additional information-processing mechanisms are needed to simulate developmental change – the transition from one stage to the next. That is, we would need to discover how the system could modify its own structure. Thus, the theory would have two parts – a program to describe performance at a particular stage and a learning program governing the transitions from stage to stage. (Simon, 1962, pp. 154–155)

Yes, Herb Simon even had something to say about cognitive development. His suggestions, published over 40 years ago in an SRCD monograph, contained two ideas that departed radically from the then-prevailing views in developmental psychology. The first idea was that a cognitive theory could be stated as a computer program from which the complex implications of the theory could be unambiguously derived. The second idea was that, if different *states* of cognitive development could be described as programs, then the developmental process itself could also be described as a program that transformed the earlier program into the later one. Such a program would be a computational model possessing some of the same self-modification capacities as the child's developing mind.

This two-step view – i.e. first construct a performance model and then seek an independent set of 'transition mechanisms' that operate on that performance model – was influential in the early years of computational modeling of cognitive development (Baylor & Gascon, 1974; Klahr & Siegler, 1978; Klahr & Wallace, 1976; Young, 1976). The introduction of connectionism (Rumelhart & McClelland, 1986), with its focus on change mechanisms, reversed the priority of attention to these two steps, but it continued the differential emphasis on one at the expense of the other. That is, the focus in most connectionist models was on learning, and although the models learned a lot, they really didn't do much with what they had learned – at least not with respect to higher-order thinking and problem-solving.

However, in recent years, the learning–performance distinction has become intentionally blurred by the creation of models that are always undergoing self-modification, even as they perform at a given 'level' or 'stage'. From the symbolic camp, perhaps the best exemplars of that kind of computational model can be seen in the hybridization of production-system architectures such as Anderson's ACT-R model and its direct application in accounting for some classical developmental phenomena, ranging from past-tense acquisition (Taatgen & Anderson, 2002) to balance scale problems (van Rijn, van Someren & van der Maas, 2003). From the connectionist side come the types of models described in this special issue. These four papers go beyond the most widely known types of connectionist models – those that use feed-forward processes and backpropagation learning, and introduce a new 'bag of tricks' – and quite powerful tricks at that – including autoassociators, Hebbian learning, adaptive resonance theory and evolutionary computation. These are important developments for developmentalists, given that the fundamental challenge we face is to provide an account of the astounding, complex and intricate process of the emergence of thought and action in humans.

So count me in as a fan of this set of papers, and the theoretical explorations that they represent. But also, consider my enthusiasm as guarded, for this work – at least as presented here – has a long way to go. Perhaps the most basic problem is simply to sustain the reader's attention and comprehension, especially the reader trained in the traditional areas of developmental psychology. For the uninitiated, the proliferation of technical terms, formal notations and acronyms may be so daunting as to discourage the typical developmental researcher from attempting to master the skills necessary

Address for correspondence: David Klahr, Department of Psychology, Carnegie Mellon University, 5000 Forbes Ave., Pittsburgh, PA 15213, USA; e-mail: klahr@cmu.edu

to apply and extend this type of theoretical model.[1] A second cautionary note is that for all of its precision and elegant formalization, the ultimate assessment of these types of models rests – paradoxically – on arbitrary and vague analogical mappings between the models' behaviors and the phenomena of interest. Finally, there is the question of how these different approaches are related. With respect to a common domain of interest, these four papers show little overlap in either their proposed mechanisms or the domain of empirical phenomena they attempt to explain.[2] Perhaps at this early stage, such diversity is necessary and desirable, and, I suspect, these chapters were solicited with just a 'span' in mind. Nevertheless, it will be important in the long run to produce an account of how they all function in a single child's head.

I opened this brief commentary with a quote from Herb Simon, and I will close with one from Allen Newell – Simon's partner in pioneering the computational approach to understanding human thought. As did Simon, Newell also speculated now and then on the state of the art in developmental science. A little over a dozen years ago, he wrote:

> I have asked some of my developmental friends where the issue stands on transitional mechanisms. Mostly, they say that developmental psychologists don't have good answers. Moreover, they haven't had the answer for so long now that they don't very often ask the question anymore – not daily, in terms of their research. (Newell, 1990, p. 462)

Newell's lament was mainly true in 1990, if evaluated in terms of the proportion of journal articles and book chapters devoted to issues of transition and change. (Although even then, there existed a small but hardy band of developmentalists who had been proposing computational approaches to these issues for many years.)

---

[1] I believe that the rapid dissemination of connectionism was due, in no small part, to the accessibility of PDP modeling techniques, provided by the tutorials and software that accompanied the groundbreaking PDP book (Rumelhart & McClelland, 1986). Although a somewhat similar compendium of production-system approaches to developmental issues was published about the same time (Klahr, Langley & Neches, 1987) it lacked the necessary tutorials and easy to use software, and its impact on developmentalists was much less widespread.

[2] Surprisingly, among the 200 or so references in these four papers, there are only two specific papers that are jointly cited and only a handful of common references even to the same body of work.

However, as in the case of Simon's opening comment, the papers presented in this special issue attest to the fact that as a field progresses, even the views of the giants in that field can become historically interesting, but no longer valid. These four papers clearly demonstrate not only that some of the most innovative investigators in the area of developmental science *are* asking questions – and daily – about transitional mechanisms, but also that they are proposing some intriguing and creative answers.

References

Baylor, G.W., & Gascon, J. (1974). An information processing theory of aspects of the development of weight seriation in children. *Cognitive Psychology*, **6**, 1–40.

Klahr, D., Langley, P., & Neches, R. (Eds.) (1987). *Production system models of learning and development*. Cambridge, MA: MIT Press.

Klahr, D., & MacWhinney, B. (1998). Information processing. In D. Kuhn & R.S. Siegler (Eds.), W. Damon (Series Ed.), *Handbook of child psychology* (5th edn.), *Vol. 2: Cognition, perception, and language* (pp. 631–678). New York: Wiley.

Klahr, D., & Siegler, R.S. (1978). The representation of children's knowledge. In H.W. Reese & L.P. Lipsitt (Eds.), *Advances in child development*, Vol. 12 (pp. 61–116). New York: Academic Press.

Klahr, D., & Wallace, J.G. (1976). *Cognitive development: An information-processing view*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Newell, A. (1990). *Unified theories of cognition*. Cambridge, MA: Harvard University Press.

Rumelhart, D.E., McClelland, J.L., & the PDP research group (1986). *Parallel distributed processing: Explorations in the microstructure of cognition*. Cambridge, MA: MIT Press.

Simon, H.A. (1962). An information processing theory of intellectual development. *Monographs of the Society for Research in Child Development*, **27**.

Taatgen, N.A., & Anderson, J.R. (2002). Why do children learn to say 'broke'? A model of learning the past tense without feedback. *Cognition*, **86** (2), 123–155.

van Rijn, H., van Someren, M., & van der Maas, H. (2003). Modeling developmental transitions. *Cognitive Science*, **27** (2), 227–257.

Young, R.M. (1976). *Seriation by children: An artificial intelligence analysis of a Piagetian task*. Basel: Birkhauser.