Computer Experience and Cognitive Development

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Although considerable research bears on the question of how children develop into adults, almost all is substantially removed from the reality and complexity of actual child development. Occasionally, one becomes aware of child development as a subject of study and is encouraged to see it as an important area for AI research and to believe it will one day be explained in terms satisfying to AI researchers. For example, much of Piaget's work has this flavor, and Minsky and Papert's classic 1972 MIT AI Lab Progress Report presented compelling arguments that AI provides a powerful set of techniques for studying cognitive development. In these days of applied AI, I find *Computer Experience and Cognitive Development* (Ellis Horwood Limited, Chichester, England, 1985, 275 pp., $28.95) by Robert Lawler to be a refreshing and thought-provoking reminder that explaining how children develop into adults is exceedingly important; exceedingly hard; exceedingly interesting; and, possibly, answerable.

Lawler's intent is to present a theory of the "development of mind" within a child. Although "mind" is a broad topic, and development is complex, he succeeds remarkably well. His theories are based on three sources. First, Lawler performed extensive and participatory naturalistic observations of his daughter Miriam as she learned a number of different tasks. Second, he adopts an approach to AI that draws heavily on Minsky's society of minds and Papert's LOGO laboratory research. Third, Lawler believes that the body of Piaget's work represents the form and flavor which an integrated theory of the development of mind should take and that Piaget has identified many of the underlying processes of development. Thus, Lawler explains his observations of his daughter's cognitive development in computational terms derived from a synthesis of Piagetian theory and modern AI.

Computer Experience and Cognitive Development is, however, a difficult book to read. Although Lawler's descriptions of Miriam's learning are excellent, his descriptions of his theories are at times difficult to follow. They are expressed only in the most general computational terms. I found myself drawing on years of programming experience to understand him. He frequently and distractingly intermixes data, theory, and philosophy. His statements of the goals of various parts of the book and his conclusions are couched in Piagetesque and individualistic terms and often are only vaguely defined. His diagrams require more study than should be necessary, and several confusing typographic errors appear here and there. Given the choice between a sacrifice of clarity and one of content, Lawler's choice of content was correct, but one wishes for both. I continue to think about this book, considering how the author's theories might be expanded, computer models of the data he presents might be constructed, and his ideas might be applied to my own book; this recommendation is the best of all.

Lawler's book draws on something called "the intimate study," in which Lawler spent six months participating in, and observing the details of, his six-year-old daughter's learning in a number of different areas, with less detailed followup observations. For example, Lawler describes Miriam learning to add, debug LOGO programs, and play tic-tac-toe. Excerpts from his observations and the primary data he seeks to explain are presented throughout the book. These excerpts are naturalistic observations of events, learning situations, and teaching situations in which Lawler himself actively participated. Some might dislike Lawler's departure from methodological rigor in this regard, but I believe that Lawler has skillfully and sympathetically captured the essential reality of this development and that no other technique would do as well.

The role of computer experience ascribed by Lawler to Miriam's cognitive development and his own theories is ambiguous, the title notwithstanding. Some have argued that giving children the correct sort of computer experience can act as a developmental accelerator and guidance system, enabling the child to develop more rapidly and with a greater facility in certain modes of thought; superficially, Lawler appears to fall within this camp. Miriam was heavily involved with LOGO programming during the intimate study, and about half of Lawler's observations concern her computer experience. However, the title *Computer Experience and Cognitive Development* might be somewhat misleading; this book is not trying to be a version of Papert's argument that "computers give children access to powerful ideas." Instead, the computer serves two purposes for Lawler. First, records of Miriam's growing mastery of LOGO serve as a kind of audit trail of her cognitive development and provide Lawler with primary data in a number of important areas. Second, Lawler's primary metaphor for cognitive development is, essentially, computer programming: Cognitive development is the programming of the mental computer. In this regard, Lawler lies directly within mainstream AI.

Lawler explains Miriam's development in Piagetian terms such as "the equilibration of cognitive structures," "genetic epistemology" (which seeks the sources of knowledge in prior knowledge), and "the articulation of complementary roles." Unlike Piaget, however, Lawler's theories give computational meaning to such terms. Lawler argues, for example, that Miriam learns to add by first learning specific procedures which can be applied only to certain objects: She learns to add coin values in a particular way, for example, and angle and range values in the context of the cue in the LOGO billiards game in some other way, using various cognitive predecessors. General counting expertise develops when several different procedures are executed and produce different answers for the same problem. This unexpected difference of opinion by two procedures within what Lawler views as a small society of minds is what catalyzes development. When this occurs, the two procedures are embedded within a more general control structure that decomposes the problem into parts, selectively invokes each procedure for the appropriate part, and combines their results to solve the problem as a whole. This process is explicitly equivalent to a child writing small LOGO procedures to, say, draw a picture. Lawler explains Miriam's learning to add in terms of genetic epistemology but supplies an explicit computational foundation for this notion, which is lacking in Piaget's work.

The acquisition by Miriam of the ultimately correct procedure for adding does not develop, as might be expected, as a result of a generalizing of the various context-specific addition procedures or a complex "case statement" indexing the context-specific procedures for every possible context. Rather, Lawler argues, learning the correct addition procedure is not unlike the original learning of the context-specific procedures as the combination of cognitive predecessors and, indeed, requires significant amounts of straightforward instruction. However, without the prior development of the context-sensitive addition procedures and their assembly into higher-level structures, Lawler adds, the child would not be able to understand that this new addition procedure she was learning was a generalization of the context-specific procedures she had learned. Moreover, she would not be able to understand the abstract representations within the general procedure and the abstract purposes of the steps in the procedure and would not be able to learn the generalization. Thus, Lawler argues that Miriam's earlier learning provided a kind of cognitive scaffolding without which more advanced learning could not take place.

Lawler's descriptions of child learning and his use of a computational metaphor to describe this learning are extensive in scope, and he presents data on a number of different areas. First, he describes how his son Robby learns to draw pictures using the LOGO drawing program. He proposes that the use of prior knowledge of tinker toys (the tinker-toy "microview") enabled Robby to understand how to command the LOGO turtle to correctly make the triangular roof of a house and, thus, contribute to the development of the LOGO drawing program microview. He explores how Robby's context-specific knowledge in one area is required in order to understand and acquire knowledge about another area, how problem solving is governed to some degree by fortuitous matching of the results of an action and an inactive goal, and how the child applies old procedures in new situations by making constants variables in his procedures.

Lawler then addresses a very Piagetian idea: the invariance of stage development. According to Piaget and most of psychology for that matter, children's cognitive abilities progress through a series of stages, and the order of these stages is more or less invariant. Lawler explores this concept through the use of LOGO programming and, particularly, Miriam's learning to debug her own LOGO programs. Lawler argues that certain elements of advanced, formal thought can exist in certain areas, such as LOGO programming, prior to less advanced concrete thought; LOGO programming can be instrumental in the emergence of formal thought; and formal thought developed within the LOGO context can be generally applied to other areas of the child's life. Lawler concludes that the stage model paradigm requires substantial revision, and "that formal thought, in the Piagetian sense, is a competitor with concrete thought, not an emergent from its perfection" (p. 23). In addition to its primary focus on the issues of stages, Lawler also considers the role of the computer as developmental accelerator and guidance system and discusses the child's acquisition of the debugging metaphor while learning to program and use of the metaphor in learning in a variety of areas. He concludes that learning LOGO programming (and debugging in particular) is important for Miriam, a conclusion that seems quite plausible. Unfortunately, however, Lawler does not discuss the extent to which Miriam's development could be accelerated and guided by the cooperative and concentrated attention of highly intelligent adults who want to introduce her to exciting, advanced technology primarily designed for fun.

Frequently, there is more to what Lawler presents than what he discusses; the best example of this lies in Lawler's discussion of how Miriam learned to play tic-tac-toe. Now, I had always thought of tic-tac-toe as a pretty simple game that makes a good low-level programming assignment. One can take a Samuels-type approach to learning to play tic-tac-toe or a concept learning approach or a learn-a-new-rule-when-you-lose approach, but I never thought you could learn much from studying tic-tac-toe. After reading Lawler, I have decided I am quite wrong. His description of how Miriam learned to play tic-tac-toe reveals an extremely complex process. To me, the description of Miriam learning tic-tac-toe was a forceful and vivid statement of how complicated children's learning really is and how irrelevant abstract simplications of the learning process can be. Although Lawler does no more than present his observations and a high-level theory to explain them, it is clear that a computer model of how Miriam learned to play tic-tac-toe could be developed; this discovery is the most exciting of all.

What is important to Lawler in this learning process is how (1) learning to play tic-tac-toe revealed the importance of an "other" in development, (2) how it revealed the importance of the child's ability to think from the point of view of this other, and (3) how the development of the ability to manipulate her own mental environment and think about her own thoughts is central to overall development. Without social interaction, child development does not proceed, and Lawler's descriptions of this interaction in a specific case offer a framework to guide the investigation of other cases. Lawler also uses this learning example to investigate the development of hierarchies of microviews from a different perspective. He discusses learning to play tic-tac-toe as a process very similar to learning to add: Isolated microviews of context-specific knowledge are coordinated and modified to encompass more and more of the game. As with Miriam, a central factor in this coordination and modification is the ability to mentally play against oneself, and to explore and learn strategic play by restricting the mental opponent simply to tactical play. These propositions seem correct, and the identification and description in computational terms of the vital social role and the importance of reflective thought in child development, although not new, was presented in an entirely unique, detailed, and computationally meaningful way.

Lawler concludes with an interesting thought. Throughout the book, he explains the development of cognitive abilities in terms of the combination and modification of earlier abilities in response to various experiences. The question to ask is: What are the original cognitive abilities? Lawler believes the original cognitive abilities are derived from five "sensorimotor subsystems," each organized around five major body parts. That is, Lawler proposes cognitive development has a specific biological origin. This proposal is interesting and provides a foundation for the later development discussed in the rest of the book.

Overall, Lawler's *Computer Experience and Cognitive Development* provides a coherent view of child development and learning in terms familiar to AI researchers. One can dimly discern the outlines of computer programs that would model Miriam's learning within Lawler's descriptions and theories and herein lies the central contribution of Lawler's book: You read it and start to think that he has been observing and describing some fundamental aspects of the development of intelligence and, furthermore, that a computer model of this development might be within reach. I think *Computer Experience and Cognitive Development* could be an important book for AI, notwithstanding a certain degree of stylistic opacity, because it represents a high point of AI research into child development and suggests a methodology and a theoretical approach to computer models of child development that capture its essence. I think the development of computer models embodying Lawler's theories would be significant research, and I hope that Lawler or one of his students will develop such models. A computer program that learns to play tic-tac-toe the way Miriam did or learns to add the way Miriam did would really be an achievement.

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