Learning About Learning

Robert S. Siegler, Carnegie Mellon University

The field of children’s learning was thriving when the *Merrill-Palmer Quarterly* was launched; the field later went into eclipse and now is in the midst of a resurgence. This commentary examines reasons for these trends, and describes the emerging field of children’s learning. In particular, the new field is seen as differing from the old in its emphasis on variability, choice, and change as central aspects of children’s functioning and in its reliance on high-density sampling of learning, of the type provided by microgenetic methods. Examples of learning in content areas ranging from motor development to problem solving to attention, and with age groups ranging from infants to adults, are used to illustrate the insights that this new field is yielding.

The prominence of the area of learning within developmental psychology has varied widely over the *Merrill Palmer Quarterly*’s first 50 years. In the journal’s first decades, the 1950s and 1960s, the area of children’s learning occupied a central place within the field of child development. Consider the following observation from the chapter on children’s learning in *Carmichael’s Manual of Child Psychology* that covered the period 1954 to 1970:

The number and quality of studies on children’s learning published each year have continued to increase. . . . By now there have been so many studies of children’s learning that it is impossible to review them adequately in one chapter. . . . Because of the vast number of publications, no attempt is made to include all possibly relevant studies. (Stevenson, 1970, pp. 849, 851, 852)

Soon after Stevenson’s observation, however, the study of children’s learning drastically declined. When Stevenson reviewed developments

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Robert S. Siegler, Department of Psychology.

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Correspondence should be addressed to Robert S. Siegler, Department of Psychology, Carnegie Mellon University, Pittsburgh, PA 15213. E-mail: rs7k@andrew.cmu.edu.

in the field of children’s learning between 1970 and 1983 in the next edition of the *Manual* (now called *The Handbook of Child Psychology*), his observation could hardly have been more different:

By the mid-1970’s, articles on children’s learning dwindled to a fraction of the number that had been published in the previous decade, and by 1980, it was necessary to search with diligence to uncover any articles at all. (Stevenson, 1983, p. 213)

The reasons for this decline in the study of children’s learning are well known and have been discussed elsewhere (e.g., Brown, Bransford, Ferrara, & Campione, 1983; Siegler, 2000). Simply put, the decline of the field, along with the learning theory approach on which it was based, reflected both the limitations of the approach and the emergence of attractive alternatives. The tasks emphasized by learning theory, often derived from tasks used with nonhuman animals, generally bore only an abstract resemblance to the types of tasks that children learn in their daily lives. The learning theory assumption that acquisition processes were basically the same regardless of species, age, or knowledge precluded from consideration issues near and dear to the hearts of many developmentalists, such as developmental, individual, and species differences in learning. The depiction of children as passive organisms, dependent on the environment to stamp in connections, also was unappealing to a wide range of developmentalists.

Thus, when the alternative of Piagetian theory was presented in a clear, appealing form in John Flavell’s (1963) influential book, *The Developmental Psychology of Jean Piaget*, the ideas found a ready audience. Although Piagetian theory had been evolving since the 1920s, the lack of translation of many works; the absence of clear, brief, integrative summaries of the central tenets of the theory; the difficult and unfamiliar vocabulary; and the idiosyncratic methodology that Piaget adopted to study children limited its appeal. However, Flavell’s compelling summary of the theory made clear its many intriguing aspects, as well as the many controversial claims that would stimulate a new generation of research.

The rise of Piaget’s theory contributed to the temporary demise of the study of children’s learning not only because it led cognitive developmentalists to focus on other problems but also because Piaget drew a strict distinction between development and learning that dignified the one and devalued the other. This is evident in Piaget’s article on the relation between learning and development:

The development of knowledge is a spontaneous process, tied to the whole process of embryogenesis. Learning presents the
opposite case. In general, learning is provoked by situations—provoked by a psychological experimenter; or by a teacher, with respect to some didactic point; or by an external situation. It is provoked, in general, as opposed to spontaneous. In addition, it is a limited process—limited to a single problem, or to a single structure. (1964, p. 7)

A second major influence on the field of cognitive development in the 1970s and 1980s, information processing theories, also contributed to the shift away from the study of learning, albeit for a different reason. Within information processing theory, learning always has been viewed as central to development, but the strategy adopted by information processing researchers was first to describe in detail the beginning and end states of development and only then to focus on how children progress from the one to the other (Klahr & Wallace, 1976). Not until relatively recently have significant numbers of researchers who take an information processing approach to development begun to focus on learning (e.g., Munakata & McClelland, 2003).

This increasing focus on children’s learning by researchers who take an information processing approach is part of a larger trend. The field of children’s learning is undergoing a revival, driven not only by information processing researchers but also by those who take sociocultural (e.g., Gauvain, 2001), theory-theory (e.g., Amsterlaw & Wellman, 2003), dynamic systems (e.g., Smith, Thelen, Tizker, & McLin, 1999), and neural approaches (e.g., Johnson, 1998). The eventual resurgence of the field was inevitable; learning is such a central part of children’s lives that minimizing attention to it can only lead to an imbalanced perspective on development. Although the degree of focus on any given fundamental issue in a scientific area waxes and wanes, those fundamental issues that have fallen into eclipse always return to prominence. The emergence of a new field of children’s learning is one such case.

The New Field of Children’s Learning

The resurgence of the field of children’s learning reflects both theoretical and methodological innovations. As has often been noted, these two types of innovations generally have a mutually facilitative influence. For example, the advent of dynamic systems theories as an approach to motor development was in part prompted by the advent of increasingly sophisticated technologies for tracing the dynamics of physical movement (e.g., Zernicke & Schneider, 1993). The precise data
yielded by these methods, in turn, has stimulated further theoretical development in the area (cf. Bertenthal & Clifton, 1998).

Another example of this mutually facilitative relation between theoretical and methodological progress, the one that will be emphasized in the remainder of this article, is that between overlapping waves theory and microgenetic methods. Trial-by-trial assessments of children's problem-solving strategies, which themselves were made possible by video recording technology, revealed far greater strategic variability than envisioned by Piagetian, information processing, or other theories (e.g., Siegler, 1987). Overlapping waves theory is an attempt to describe this strategic variability and to explain how and why the mix of strategies changes with age and experience. The theory is based on the assumption that the evolution of children's strategies, like the evolution of species, is based on processes of variability, choice, and change. In particular:

1. Assumptions regarding variability:
   a. Children of a given age typically know and use a variety of strategies and conceptions, rather than just a single one, for solving a class of problems.
   b. This is true for individual children as well as for groups of children.
   c. Even on a single problem presented on several occasions close in time, an individual child often will use multiple strategies.
   d. The diverse strategies and conceptions coexist over prolonged periods, rather than the variability being limited to special transition periods.

2. Assumptions regarding choice:
   a. Children generally adjust their choices of strategies to problem characteristics, most often choosing the fastest strategy from among those they know that are likely to yield accurate performance on the particular problem.
   b. Strategy choices are often quite adaptive from early in learning, but they tend to become more adaptive with experience.

3. Assumptions regarding learning:
   a. Learning occurs through at least four processes: acquisition of new strategies; increasing reliance on the most effective approaches within the set of strategies that are already known; superior choices among strategies; and
increasingly fast, accurate, and effortless execution of strategies.

b. Strategic change is usually a gradual process; discovery of a superior new strategy is often only the first step toward consistent use of the new approach.

The following sections briefly examine evidence relevant to these assumptions regarding variability, choice, and change.

**Variability**

A major innovation of the new field of children’s learning in general, and overlapping waves theory in particular, is their emphasis on cognitive variability. Assessing strategy use on a trial-by-trial basis has revealed use of multiple strategies on a wide range of tasks, including arithmetic (Geary & Brown, 1991), selective attention (Miller & Aloise-Young, 1996), language production (Marcus et al., 1992), serial recall (Coyle & Bjorklund, 1997), scientific experimentation (Schauble, 1996), and biological reasoning (Opfer & Siegler, in press). On most of these tasks, individual children have been found to use three or more approaches on different problems. This already is very different from the depiction within traditional theories, but the reality is even more different. The same child, presented the same problem on two occasions close in time, often will use different strategies. In both preschoolers’ addition (Siegler & Shrager, 1984) and elementary school children’s time-telling (Siegler & McGilly, 1989), one third of children used a different strategy on the second presentation of a problem, within a week of the original presentation. The strategy changes were not in general attributable to learning; roughly 55% of shifts were from less advanced to more advanced strategies, but 45% were in the opposite direction.

Strategic variability is not unique to children. For example, Dowker, Flood, Griffiths, Harriss, and Hook (1996) examined estimation strategies on multidigit multiplication and division problems of four groups of adults: mathematicians, accountants, psychology students, and English students. The adults’ strategies were remarkably diverse: for example, the 176 participants used 27 different strategies for solving the single problem 4645 ÷ 18. Across the problem set, individuals in each of the four disciplines averaged more than five strategies apiece. In line with one of the most distinctive predictions of overlapping waves theory, strategic variability was evident within individual and problem. Thus, when the same problems were presented to participants a second time, mathematicians used a different strategy on 46% of items and psychology students on 37%.
As suggested by the Dowker et al. (1996) findings, strategic variability is characteristic of cognition throughout life, rather than being restricted to special transition phases. Evidence for this statement has emerged from some surprising places. For example, despite single-digit arithmetic being an extremely overlearned task, substantial strategic variability is present among 4- and 5-year-olds (e.g., Geary & Burlingham-Dubre, 1989), 9- and 10-year-olds (Goldman, Mertz, & Pellegrino, 1989), and 18- to 23-year-olds (LeFevre, Sadesky, & Bisanz, 1996). Senior citizens (65- to 85-year-olds) show similar strategic variability in multidigit arithmetic (Siegler & Lemaire, 1997). Most participants in these studies, regardless of age, used at least three strategies.

Recognizing the pervasiveness of such variability is important for understanding learning. At the level of individual differences, the amount of initial strategic variability tends to be predictive of subsequent learning. Subsequent learning has been found to correlate with several measures of initial (pretest) variability: greater number of strategies, multiple strategies on a single problem, gesture-speech mismatches, and frequent self-corrections and deletions in self-reports of strategy use (e.g., Alibali & Goldin-Meadow, 1993; Perry & Lewis, 1999; Siegler, 1995).

Variable strategy use also plays an important role within the detailed theoretical accounts of learning provided by computer simulations. For example, within Shrager and Siegler's (1998) SCADS (Strategy Choice and Discovery Simulation) model of addition, generation of new strategies was heavily dependent on combining relevant parts of existing strategies. A similar logic generated new productions within Holland's (1986) genetic algorithm model. In such models, the greater the variety of existing strategies, the greater the potential for combining relevant pieces into new, superior approaches.

Not all kinds of variability are positively related to learning. For example, variability of strategy use between successive trials tends to be negatively related to correct recall (Coyle & Bjorklund, 1997). The likely reason is that learners apply the win-stay lose-shift heuristic; children change strategies more often following unsuccessful performance (McGilly & Siegler, 1989), which can lead to negative correlations between trial-to-trial strategy shifts and accuracy. Similarly, strategies that are so flawed that they place the learner in a position that is not useful for exploring the task environment seem unlikely to promote learning. Extremely variable golf swings, for example, may lead to less learning than moderately variable swings, because the extreme variability precludes interpretable feedback regarding effective procedures. Determining which types of variability are positively related to learning
and which are not seems likely to result in improved understanding of how learning occurs.

**Choice**

Throughout life, people choose strategies in adaptive ways. Such adaptive strategy choices both produce and are produced by learning. The pattern is already evident in infancy. Adolph (1997) created a situation in which mothers of infants beckoned their babies to descend ramps of varying steepness to where the mother awaited them. A microgenetic design was used, in which babies returned to the laboratory and were presented the slopes every three weeks. This allowed examination of the babies’ descent strategies at a given age, after a given amount of experience with the mode of locomotion, and after a given number of sessions practicing the descent task.

Most babies altered their descent strategies to the slope of the ramp in highly adaptive ways. When the angle was reasonably shallow, they used their usual mode of locomotion (crawling or walking) to descend; as the slope became steeper, they became increasingly likely to adopt safer strategies, such as sliding down on their belly or behind. These choices allowed quick and safe descent when the infants’ usual mode of locomotion would allow such an outcome, and slower but safe descent when it would not.

The adaptiveness of the babies’ strategy choices increased with experience with the particular mode of locomotion. Thus, during the period in which crawling predominated, infants became ever more sensitive to which slopes they could descend safely and which required them to lower their center of gravity. However, when the infants began to walk, their choices became less adaptive than they had been when the infants were crawling; some infants became more cautious than necessary, whereas others took risks that would have been dangerous if adults had not been present to catch them. Experience with walking soon brought a return to highly adaptive strategy choices. Thus, strategy choices became steadily more adaptive within a given mode of locomotion, but the process had to start anew when the infants switched their predominant locomotor modality.

Adolph’s (1997) data illustrated how adaptive strategy choice both facilitates learning and reflects it. The infants’ choices of locomotor strategies were fairly adaptive from the beginning; infants usually did not try to crawl or walk down the steepest slopes, and they consistently used their predominant mode of locomotion on flat surfaces and shallow slopes. However, as they gained experience using their predominant
mode of locomotion, the babies’ strategy choices became more precisely calibrated to the angles that they could traverse without falling. The relevant type of experience turned out not to be experience with the slopes themselves but rather general experience with crawling or walking. Evidence for this conclusion was provided by an age-matched control group that was presented the descent task only three times: at the outset of the study, ten weeks after that, and when their parents reported that they started walking. At all points, their performance was comparable to that of control-group babies who received experience descending the slopes every three weeks. Moreover, changes in the adaptiveness of strategy choices were positively correlated with the duration of infants’ everyday experience with crawling and walking.

**Change**

The overlapping waves model suggests at least four sources of strategic change: acquisition of new strategies, increasing use of relatively advanced strategies within the set that children use at any given time, increasingly adaptive choices among strategies, and increasingly effective execution of whichever strategies are used (Lemaire & Siegler, 1995). First consider acquisition of new strategies. Even after children use strategies that yield consistently correct performance, they continue to invent new approaches. Children who can already solve addition problems by counting up from the number one discover that they can also solve the problems by counting up from the larger addend (Siegler & Jenkins, 1989); children who solve number conservation problems by counting discover that they can solve the same problems through logical reasoning (Siegler, 1981); adults who know numerous estimation procedures devise yet others (Dowker et al., 1996); and so on. Sometimes but not always, these new approaches allow more efficient solutions. In other cases, people devise specialized strategies that are limited in their applicability across problems but that yield fast and accurate performance on the subset of problems where they are applicable (e.g., appending two zeros to the other multiplicand when multiplying by 100). In yet other cases, a new strategy can be either superior or inferior to existing ones, depending on when it is used; subtracting by counting up rather than counting down is one such case. Thus, learning frequently reflects acquisition of new strategies.

Another source of cognitive change is increasing reliance on the more sophisticated strategies from among those that children already use. Even after children discover new strategies and can explain why
the new strategies are superior to their previous ones, they still often use the older, inferior approaches. For example, even after toddlers learned which type of tool would be most effective in pulling in a desirable toy, they still often reverted to less effective approaches, such as reaching or using ineffective tools (Chen & Siegler, 2000). Similarly, although 6-year-olds recognize the superiority of systematic experimentation strategies to unsystematic ones (Sodian, Zaitchik, & Carey, 1991), and although 10-year-olds sometimes generate systematic experiments (Schauble, 1996), even adults often generate unsystematic ones (Schauble, 1996). Much learning involves not replacement of inferior approaches by superior ones but, instead, slowly increasing reliance on the superior approaches.

A third source of cognitive change is increasingly adaptive choices among strategies. Even if the frequency of use of each strategy remains constant, learning can occur in the precision with which strategies are fitted to problem characteristics. For example, a study involving French 2nd graders who were learning single-digit multiplication indicated that their strategy choices were fairly adaptive within 10 days of their initial instruction in the skill. However, subsequent examination of the same children indicated that the precision of their strategy choices was greater two months later and that it was still greater two months after that (Lemaire & Siegler, 1995). To be specific, problem difficulty (defined in terms of mean solution time for the problem) became increasingly correlated with how often children used strategies other than retrieval on the problem, such as adding one of the multiplicands the number of times indicated by the other. The correlation increased from $r = .50$ to $r = .75$ to $r = .80$ over the three occasions.

The fourth source of cognitive change is the efficiency with which strategies are executed. Even if children continue to use identical strategies on identical problems, learning can still occur in the speed and accuracy with which they execute the strategies. This is another omnipresent source of learning. For example, Chen and Siegler (2000) found that over two tool-use problems, 18- to 26-month-olds increased their likelihood of successful execution of the tool-use strategy on trials in which they used the optimal tool from 57% to 76% in one condition and from 75% to 91% in the other. Similarly, the speed with which the toddlers obtained the toy increased both on successive trials within the same problem and across problems. Newell and Rosenbloom’s (1981) review of the literature on the practice law of learning documents the pervasiveness of such improvements in efficiency of strategy execution.
Learning and Development

Unlike learning theory approaches, the overlapping waves model and other approaches to the new field of children’s learning have highlighted questions of traditional concern to developmentalists—for example, developmental differences in learning. One approach to this issue has been to compare microgenetic and age-related change. There is widespread agreement that there is some resemblance between the relatively rapid changes that emerge in microgenetic studies and the more slowly emerging changes that are documented in cross-sectional and longitudinal designs (e.g., Fischer & Biddell, 1998; Granott, 1998; Miller & Coyle, 1999). However, the degree of the resemblance remains a matter of dispute. This issue led Miller and Coyle to conclude, “Although the microgenetic method reveals how behavior can change, it is less clear whether behavior typically does change in this way in the natural environment” (p. 212; italics in original).

To address this issue, Siegler and Svetina (2002) combined microgenetic and cross-sectional components within the same design in a study of matrix completion. This task was chosen because it is prominent within Piagetian, information processing, and psychometric traditions alike and because it assesses inductive reasoning capabilities relatively directly. At the outset of the study, Slovenian 6-, 7-, and 8-year-olds were presented the standard matrix completion task to provide a cross-sectional perspective on development. Then, half of the 6-year-olds (those in the experimental group) were presented an additional five sessions, 22 matrix-completion problems per session, within a three-week period. On each problem, the children in this condition were provided feedback on whether their choice, from among six alternative answers, was correct; then the children were told the correct answer and asked to explain why that answer was correct. Seven weeks later, the 6-year-olds in this experimental group and their age peers in the control group, who had not participated since the first session, were presented a final session of matrix-completion problems without feedback.

Children in the experimental condition improved their percentage correct from pretest to posttest significantly more than did peers in the control group. The overall amount of change from the first through the seventh session in the experimental condition was virtually identical to the amount of change between ages 6 and 7 years in the cross-sectional part of the study. Therefore, the detailed patterning of microgenetic change was compared to that of cross-sectional change in this age range.

The patterning of changes—and nonchanges—proved to be closely comparable. The two groups matched on 10 of the 11 indices of change that were examined; significant change occurred over the seven sessions
and over the one-year period on 5 indices of change and over neither sessions nor years on 5 other indices. The specificity of the matches was often quite impressive. For example, significant changes over both sessions and years were present in the number of answers that were correct on the size dimension, but no changes were present over sessions or years in number of explanations that mentioned size. Similarly, the predominant type of error was the same in the experimental group in all seven sessions and in the cross-sectional part of the study at both ages 6 and 7 years.

The microgenetic portion of the study also yielded data that could not have been obtained within any traditional cross-sectional or longitudinal design. For example, results from the experimental condition indicated that rejecting existing approaches and generating superior new approaches were separate processes. Children in the experimental condition shifted away from their predominant error on about a dozen trials before they discovered how to solve the problems correctly. During the interim, they generated a variety of incorrect approaches, as well as generating occasional correct answers (as they had previously).

Similar temporal separations between rejecting previous predominant approaches and inventing superior alternatives have emerged in other microgenetic studies of learning, including studies of learning about balance scales, number conservation, and mathematical equivalence (Alibali, 1999; Siegler, 1995; Siegler & Chen, 1998). Whether a similar separation between rejecting predominant prior approaches and generating superior new approaches also is present when development occurs under more typical conditions remains an open question. However, as the example illustrates, the new field of children’s learning is raising crucial issues, and producing relevant data, concerning how children learn.

**Predictions**

The resurgence of the field of children’s learning is likely to continue; in fact, the prominence of the area seems likely to increase further. The inherent importance of learning within children’s lives, the development of methodological tools such as microgenetic methods for capturing both quantitative and qualitative aspects of learning, and the advent of theories that emphasize learning all militate in this direction.

One direction that this expansion may take is increasing integration of microgenetic and computer simulation approaches to learning. The two methods have a natural fit. Computer-simulations of learning often generate highly specific predictions that can be tested only
through the type of high-density observations of learning that micro-
genetic studies yield. Conversely, microgenetic data are especially help-
ful for shaping and refining computer simulations of learning, because
they provide detailed constraints on the output that such models must
produce.

A good example of both advantages is provided by the interplay of
computer simulations and microgenetic research regarding preschool-
ners’ discovery of the counting-on strategy in basic addition. The
counting-on strategy involves starting at the larger addend and count-
ing upward the number of times indicated by the smaller addend; thus,
on both $2 + 5$ and $5 + 2$, a child who used the counting-on strategy
would say, “5, 6, 7” or “6, 7.” Cross-sectional studies (e.g., Groen &
Parkman, 1972) had shown that in the early elementary school years,
children often use the counting-on strategy, although younger children
often count from one and older children often retrieve answers to such
problems. Based on such findings, Neches (1987) built a comput-
simulation model of the discovery of the counting-on strategy. The
model started by counting from one, then discovered the strategy of
counting from the first addend, and then discovered the counting-on
approach. This model was consistent with the limited data on learning
that the cross-sectional studies had yielded.

However, a microgenetic study (Siegler & Jenkins, 1989) that exam-
ined preschoolers’ addition on a trial-by-trial basis demonstrated that
the Neches (1987) model needed to be reformulated. One reason was
that not one child in the study counted from the first addend before
using the counting-on strategy, and few children ever used the approach
on trials where the first addend was smaller than the second (the only
trials that discriminate between the two approaches). Thus, counting
from the first addend was not transitional to the counting-on strategy.
On the other hand, the microgenetic data did indicate that children
used a transitional strategy between counting from one and counting-
on, but the transitional approach involved a shortcut version of count-
ing from one (the shortcut sum strategy; see Siegler and Jenkins, 1989,
for details).

This and other aspects of the microgenetic data from Siegler and
Jenkins (1989) provided a large number of useful constraints for gener-
ating a new computer simulation model of acquisition of the counting-
on strategy. The new model (Shrager & Siegler, 1998) discovered the
transitional strategy that children in the microgenetic study used; took
about the same number of trials to discover the transitional and
counting-on strategies as did children; generalized use of the counting-
on strategy to new problems at a similarly slow rate as did children;
responded to challenging problems in the same way as did children (by increasing their use of the new strategy); and showed solution time, accuracy, and error pattern data much like those of children in the microgenetic study as well.

The multiple aspects of learning revealed by the microgenetic method provided useful guidance for constructing the simulation model, because it greatly reduced the range of possible models that could meet all of the behavioral constraints. At the same time, the simulation model yielded further predictions for empirical testing. This symbiotic relation between microgenetic and computer-simulation methods seems likely to promote increased joint use of the two approaches in the future.

References


