ACROSS THE GREAT DIVIDE:
BRIDGING THE GAP BETWEEN
UNDERSTANDING OF TODDLERS’ AND
OLDER CHILDREN’S THINKING

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COMMENTARY
A KEY BRIDGE TO UNDERSTANDING THE DEVELOPMENT OF THINKING AND PROBLEM SOLVING
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ABSTRACT


Research on very young children's cognitive development differs greatly from research on cognitive development in older children. The differences include the questions that are asked, the methods that are used to address them, the measures that are employed to provide relevant evidence, and the level of detail at which children's knowledge is represented. The research approaches are so different that they create an impression that infants' and toddlers' thinking differs qualitatively from that of preschoolers and older children. This impression, however, may reflect differences in research approaches rather than differences in children's thinking.

In the present study, we attempted to bridge this gap by applying to toddlers a type of process analysis that has proved fruitful in studies of older children. Overlapping waves theory, trial-by-trial strategy assessments, and microgenetic methods were used to analyze 1.5- and 2.5-year-olds' problem solving and learning. The results demonstrated that changes in toddlers' strategies could be assessed reliably on a trial-by-trial basis, that the changes followed the basic form predicted by the overlapping waves model, and that analyses of toddlers' strategies could tell us a great deal about both qualitative and quantitative aspects of their learning.

A componential analysis of learning that previously had been applied to older children also proved useful for understanding toddlers' learning. The analysis specified that cognitive change frequently involves five components: acquisition of new strategies; strengthening of the strategies in their original context; improved mapping of strategies onto novel problems; increasingly refined choices among variants of the strategies; and increasingly skillful execution of the strategies. Independent measures of these components indicated that strategic development in toddlers involves improvements in all five components. Analyses of individual
differences in learning showed that the effects of distal variables, such as age and sex, could be partially explained in terms of their influence on mastery of the components, but that the distal variables exercised additional direct effects as well.

The process of learning in toddlers closely resembled that of older children in other ways as well. Like older children, toddlers use multiple strategies over the course of learning; their choices among strategies are quite adaptive from early on; their choices become progressively more adaptive as they gain experience with the task; they switch strategies not only from trial to trial but within a single trial; their transfer of learning from one problem to the next is primarily influenced by structural relations between problems but also is influenced by superficial features; they show utilization deficiencies early in learning that they gradually overcome; and they show individual differences in learning that fall into a few qualitatively distinct categories.

Perhaps most striking, the 1.5- and 2.5-year-olds emerged as active learners, who continued to work out the lessons of previous instruction in the absence of further instruction. That is, they integrated the lessons of their own problem-solving efforts with the previous instruction in ways that magnified the initial effects of the instruction. Overall, the findings indicated that the gap can be bridged; that theories, methods, measures, and representations of knowledge typically used with older children can improve our understanding of toddlers’ problem solving and learning as well.
This preface examines change processes in toddlers' thinking. Although research on older children's cognitive development is focusing increasingly on this topic, little is known about how changes occur in the thinking of infants and toddlers. Even less is known about age-related differences in change processes within this period. Our goal in conducting the present study is to demonstrate that the type of process analysis that has proved highly informative in studying changes in older children's and adults' thinking can be equally informative in studying changes in the thinking of infants and toddlers.

In the sections below, we first describe the "great divide" that separates research on very early and later cognition. We next describe a current theoretical approach—the overlapping waves model—and a current methodology—the microgenetic method—that have been fruitfully applied to studying change processes in older children and adults. We argue that although this theory and method have not been applied to studying very young children's thinking, they should prove just as useful there as they have with older children. Then we describe the present study: what we did, what we found, and how the overlapping waves approach and microgenetic method allowed us to gain in-depth understanding of change processes in toddlers' problem solving.
I. THE GREAT DIVIDE

Current research on infants’ and toddlers’ thinking differs greatly from current research on the thinking of older children. The two bodies of research differ in the questions and issues that are emphasized, the experimental paradigms that are employed, the measures used to assess cognitive competence, and the level of detail at which thought processes are described. Some of these differences between the two bodies of research are due to inherent differences between younger and older children. Other reasons for the differences, however, are more historical and, from our perspective, unnecessary.

DIFFERENT QUESTIONS AND ISSUES

Most research on infant and toddler cognition has focused on establishing when particular competencies emerge. Among the competencies that have received extensive attention are imitation (Meltzoff, 1988), planning (Willatts, 1990), tool use (Brown, 1990), representing hidden objects (Baillargeon, 1987), forming expectations of future events (Haith, 1993), representing the number of objects (Wynn, 1998), and using external representations to find hidden objects (DeLoache, 1995). The basic theme that emerges from these and many other studies of infants’ and toddlers’ thinking can be summarized quite simply: Cognitive competencies are present, at least in rudimentary forms, at much younger ages than once suspected.

Research on infants and toddlers also has focused on developmental trends toward increasingly broad application of these early-emerging competencies. Such age-related improvements are evident in the range of causal relations that infants understand (Oakes, 1994), in the length of action sequences that they can plan (Willatts, 1990), in the set of physical symbols that toddlers can use to guide their searches for hidden objects (DeLoache, 1995), and in the rapidity with which they acquire problem-solving skills (Chen, Sanchez, & Campbell, 1997).
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The issues that are most often addressed in current studies of older children’s thinking overlap with those that are being addressed with infants and toddlers. For example, many studies of 4- to 8-year-olds focus on when they first show various competencies and on age-related improvements in the range of situations in which they exhibit these competencies. In the last decade, however, these types of research have been supplemented by an increasing number of studies aimed at revealing mechanisms of change in older children’s thinking. The need to specify such mechanisms has long been recognized. For example, Flavell (1984) commented,

Serious theorizing about basic mechanisms of cognitive growth has actually never been a popular pastime, now or in the past. It is rare indeed to encounter a substantive treatment of the problem in the annual flood of articles, chapters, and books on cognitive development. (p. 189)

Such implicit criticisms of the state of knowledge about change mechanisms, along with the inherent importance of the issue, have motivated a number of researchers who study preschoolers and older children to examine change processes empirically. These studies have already revealed quite a bit about change mechanisms, have the potential to reveal more, and have contributed to breaking down the once-rigid barrier between learning and development. In one reflection of this new focus, Kuhn (1995) commented,

In the 1960s and 1970s, development was contrasted to a simplistic, non-representational conception of learning that has little relevance today. Modern research has made it clear that learning processes share all of the complexity, organization, structure, and internal dynamics once attributed exclusively to development. If the distinction has become blurred, it is not because development has been reduced to “nothing but” learning, but rather because we now recognize learning to be more like development in many fundamental respects. (p. 138)

This increasing emphasis on change processes has been characterized as a “paradigm shift” in views of cognitive development (Granott, 1998).

One reason for the increasing emphasis on cognitive change processes is that studies that have focused on them have yielded clear commonalities regarding the basic properties of cognitive change. Consider just one of the consistent findings that has emerged—that discovery of new strategies is constrained by conceptual understanding (Coyle & Bjorklund, 1997; Gelman & Williams, 1998; Granott, 1993; Kuhn, Garcia-Mila, Zohar, & Andersen, 1995; Schauble, 1990, 1996). The novel strategies that children attempt generally make sense; they are not generated via blind trial and error. Newly generated strategies do not always yield correct
solutions to the problems that elicited them, but they usually are reasonable efforts in that direction and usually conform to the basic principles that underlie legitimate strategies in the domain. This finding has been observed in such diverse areas as scientific reasoning, arithmetic, collaborative problem solving, memory strategies, and motor skills.

This and other consistent findings regarding the basic properties of cognitive change have motivated proposals regarding the mechanisms that result in these characteristics. One example comes from the domain of single-digit addition. To account for how children discover legitimate addition strategies without ever trying illegal ones, the idea of goal sketches has been proposed (Siegler & Jenkins, 1989), tested and supported through empirical experiments (Siegler & Crowley, 1994), and formally specified as a mechanism within a computer simulation of strategy discovery (Shrager & Siegler, 1998).

The same questions about change processes that are being addressed in studies of older children’s thinking can be asked about younger children—and they are at least as interesting when applied to them. Consider one such question: Are the novel procedures attempted by infants and toddlers also constrained by conceptual understanding? No one knows. Only through direct observation of infants’ and toddlers’ construction of new procedures, and identification of the processes that give rise to the procedures, can such basic questions be answered.

**DIFFERENT METHODS**

As noted by Horowitz (1995) and by Haith and Benson (1998), the methods typically used to study infants’ cognition differ considerably from those used to study preschoolers’ and older children’s cognition. Most research on infant cognition has employed looking-time paradigms, in particular habituation and preferential looking. Although these paradigms have the advantages of standardization and simplicity, several investigators have noted difficulties in interpreting the results that they yield (Haith & Benson, 1998; Russell, 1996). In particular, it often is difficult to specify the basis on which infants are discriminating among the displays. The paradigms also yield only the dichotomous outcome “discriminates/does not discriminate.” Such depictions do not capture either the graded nature of most cognitive growth or the many small qualitative innovations that contribute so greatly to it.

Such concerns have led a number of investigators to begin using alternative paradigms that focus on infants’ and toddlers’ actions on objects. Procedures that examine reaching, sequential touching, and elicited imitation are among the most common alternatives to the looking paradigms
(Bauer & Mandler, 1992; Clifton, Muir, Ashmead, & Clarkson, 1993; Hofsten, Spelke, Feng, & Vishton, 1994; McCarty, Clifton, & Collard, 1999; Meltzoff & Moore, 1998; Willatts, 1998). Although experiments using such procedures constitute only a small minority of research on infants’ and toddlers’ cognition, they have extended knowledge in this area considerably. They have allowed examination of very young children’s thinking in more natural contexts than those of the habituation paradigm and have yielded data that reflect the graded nature of early (and later) cognition.

To date, however, neither type of method has been used much to observe ongoing changes in infants’ and toddlers’ thinking. Much of the reason goes back to the questions that have been viewed as central in the area of early cognitive development. If the question of greatest interest is “What types of capabilities are present from early in development,” standard cross-sectional methods are sufficient. If the central question, however, is “How do children acquire new knowledge,” a different type of method is necessary. In particular, to provide maximally relevant data for addressing this question, it is essential to densely sample changing competence while the changes are occurring. Without such high-density sampling of changing competence, the specifics of the change process can only be the subject of speculation.

Microgenetic methods provide the type of high-density data needed to move beyond speculation regarding the change process. Such methods involve observing children’s changing performance on a trial-by-trial basis during the period of rapid change (Kuhn, 1995; Siegler & Crowley, 1991). Studies using this approach have yielded the surprisingly consistent findings regarding cognitive change alluded to in the previous section (Kuhn, 1995; Miller & Coyle, 1999; Siegler, 1996).

Despite the usefulness of microgenetic methods for providing detailed information about cognitive change, such designs have not been used to examine infants’ or toddlers’ cognitive growth. Part of the problem is that certain means of assessing strategies on a trial-by-trial basis cannot be used with infants or toddlers. Verbal reports of strategy use provide one obvious example. Inability to use a particular measure, however, is not the same as inability to use a method; very young children’s lack of articulateness simply means that alternative measures must be identified for assessing strategy use on each trial. One such means, a means that should prove applicable in many contexts, is illustrated in the present study.

DIFFERENT MEASURES

Research on infants’ and toddlers’ thinking, whether using looking-time paradigms or other approaches, has measured cognitive competence
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primarily in terms of the frequency of desired behaviors: imitating the model, reaching to the right location, showing renewed looking when a novel stimulus is shown or when a physically impossible event seems to occur, and so on. The questions that have been viewed as central have been crucial to this choice of measures, just as they have been crucial to choices of experimental paradigms. In particular, as discussed above, if the central question is “When can children do X,” then evidence of above-chance levels of engaging in the desired behavior is highly informative. By contrast, if the central question is “How do children do X,” or “Through what process of change do children become able to do X,” then these measures tell only a small part of the story.

Research with older children and adults uses a considerably greater range of behavioral measures than does research on infants and toddlers. The additional measures include patterns of specific errors, solution-time patterns, eye movements, and verbal reports. Although infants and toddlers cannot generate very informative verbal reports, they can generate the other types of measures. Methods using such measures are frequently referred to as “process tracing methodologies,” because they allow insights into the process through which the behavior was produced.

DIFFERENT REPRESENTATIONS OF KNOWLEDGE

The questions, methods, and measures used with older children have allowed their knowledge to be described in greater detail than current descriptions of infants’ and toddlers’ knowledge. Rather than simply indicating that the child “has” the relevant competence or capability, researchers who study older children often characterize their knowledge at the level of rules, strategies, and processing components that underlie their degree of success, the particular errors they make, and their pattern of solution times. Being able to assess children’s knowledge at this relatively detailed level is crucial for examining change. Frequently, much of the increase in speed and accuracy that comes with age can be traced back to discovery of new rules and strategies (e.g., Amsel, Goodman, Savoie, & Clark, 1996; Brown & Burton, 1978; Siegler, 1987). Other times, the improved speed and accuracy reflect improved choices among alternative rules or strategies, rather than discovery of new approaches. Either way, detailed representation of children’s knowledge is crucial for understanding the change process.

To summarize the arguments in this section, current research on infants’ and toddlers’ thinking differs from research on the thinking of older children in the questions that are being asked, the experimental methods and measures that are being used to answer them, and the level
of detail at which knowledge is being represented. The gap is understandable, but it also is unfortunate. It creates artificial discontinuities in characterizations of cognitive development, artificial in the sense that they reflect changes in the way that investigators study children’s thinking rather than changes in the thinking itself. One sign that the discontinuities are artificial comes in the paradoxical conclusions that emerge from the research. Research on the cognitive capabilities of infants and toddlers generally conveys an impression that they are highly cognitively competent. Research on the cognitive capabilities of preschoolers and school-age children often conveys an impression that they are cognitively incompetent. But are preschoolers and school-age children less cognitively competent than infants and toddlers? The problem is that the gap between the questions, methods, and measures used with infants and toddlers, on the one hand, and with older children, on the other, is so great that it becomes impossible to integrate the two literatures into a coherent depiction of cognitive development. The present study is an attempt to show that in addition to this gap being undesirable, it also is unnecessary. To this end, we describe recently developed theoretical and methodological approaches that are being applied to older children’s thinking, and then describe how, in the present study, we applied these approaches to analyzing 1.5- and 2.5-year-olds’ problem solving.
II. OVERLAPPING WAVES THEORY

Overlapping waves theory (Siegler, 1996) is based on three assumptions: (a) at any one time, children think in a variety of ways about most phenomena; (b) these varied ways of thinking compete with each other, not just during brief transition periods but rather over prolonged periods of time; and (c) cognitive development involves gradual changes in the frequency of these ways of thinking, as well as the introduction of more advanced ways of thinking.

Figure 1 provides a schematic illustration of these assumptions. Looking at any vertical slice of the figure indicates that multiple approaches are used at one time. Following the curve for any strategy indicates that strategies continue to be used for protracted periods. Looking horizontally across the figure indicates that the relative frequencies of all strategies shift gradually over time, with new strategies sometimes being added and older strategies sometimes ceasing to be used. Thus, the schematic
diagram focuses attention on several key issues: the set of approaches (rather than the single approach) that children use at a given age, the factors that influence their choices among these approaches, the mechanisms that lead to changing frequencies of use of existing approaches, and the mechanisms that lead to discovery of new approaches.

Overlapping waves theory also postulates that the typical pattern of strategic development, shown in Figure 1, arises through the workings of five component processes: acquiring the strategy of interest, mapping the strategy onto novel problems, strengthening the strategy so that it is used consistently within given types of problems where it has begun to be used, refining choices among alternative strategies or alternative forms of a single strategy, and executing the strategy of interest increasingly effectively.

Acquiring new strategies is a necessary first step in strategic development; each strategy must begin to be used sometime. Such acquisition can occur through drawing analogies to better-understood problems, through forming mental models of the situation and reasoning about them, through observations made during the course of problem solving, or through direct verbal instruction (Anderson, 1991; Sternberg, 1985). Studies in which strategy use is classified on a trial-by-trial basis indicate that most children use three to six strategies to perform a given task (see Siegler, 1996, for a review of such studies). All of these strategies have to have been acquired at some point in development. Presenting children with novel tasks, or presenting them with large amounts of experience on somewhat familiar tasks, often allows observation of acquisition of new strategies (e.g., Siegler & Jenkins, 1989). Thus, the acquisition of new strategies is a fairly common event, one that is not limited to occasional transition periods and one that can be studied directly.

Mapping the strategy onto novel problems becomes essential once a strategy is acquired. Strategy acquisition inevitably takes place in a particular context. Generalizing the strategy from that context to other contexts in which the strategy is applicable can be a formidable task. The challenge is similar to that faced in vocabulary acquisition (Anglin, 1993), where the learner must be able to extend the new word to all cases in which it is applicable and to avoid extending it to cases in which it is inapplicable. As with vocabulary acquisition, successful mapping of new strategies to novel situations requires the problem solver to distinguish relevant from irrelevant aspects of the situation in which the new cognitive entity was initially acquired. Mapping the strategy to new problems on the basis of similarity between superficial features of the original and novel situations leads to the strategy being used where it is not applicable, to it not being used where it is applicable, or both. In contrast, understanding the principles that govern applicability of the strategy results in appropriate mapping of the new approach.
Strengthening the newly acquired strategy, both in the original context and in the contexts to which it is mapped, is a third component of learning. Given that children use multiple ways of thinking over prolonged periods of time, and given that some of the ways of thinking are more advanced than others, the quality of children’s thinking can improve if they increase their reliance on new, relatively advanced approaches and decrease their reliance on older, less advanced ones. Such strengthening of relatively sophisticated approaches within the existing set of approaches is a more common vehicle of cognitive growth than is commonly recognized. Both children and adults frequently fail to rely on new strategies that they have acquired, even when those strategies are considerably more effective than older alternatives (Acredolo, O’Conner, & Horobin, 1989; Church & Goldin-Meadow, 1986; Siegler, 1995). Difficulties in retrieving the new strategy and difficulties in inhibiting older strategies are likely causes of the limited use of new approaches.

Refining choices among alternative versions of a strategy is the fourth key learning component. Even if both the set of strategies and the overall frequency of each strategy remain constant, use of each strategy can be concentrated increasingly on those problems on which the strategy is most useful. This is not just a logical possibility. Although preschoolers’ and older children’s strategy choices tend to be adaptive from early in learning, the degree of adaptiveness often increases as they gain experience in the domain (Karmiloff-Smith, 1979; Lemaire & Siegler, 1995). For example, Lemaire and Siegler (1995) found that over the course of a year, French second graders who were learning single-digit multiplication increasingly often chose the strategy that yielded the most efficient performance on the particular type of problem.

Increasingly effective execution of new strategies is the fifth and final component within this analysis of learning. Even if there are no changes in the set of strategies that have been acquired, in the breadth of problems onto which each strategy is mapped, in the frequency of each strategy on both original and transfer problems, and in the precision of choices among the strategies, children’s accuracy and speed can improve greatly as they gain practice in executing each approach. In the Lemaire and Siegler (1995) study, for example, on those problems on which children retrieved answers to a given multiplication problem at all three times of measurement, percentage of errors decreased from 23% to 2%, and mean solution time decreased from 4 s to 2 s. Utilization deficiencies, in which use of a new strategy does not lead to enhanced performance until their execution of the strategy improves, also illustrate the importance of this source of development (Coyle & Bjorklund, 1997; Miller & Seier, 1994).

These five components of strategic change—acquiring, mapping, strengthening, refining, and executing—are illustrated in Figure 2, in rough
sequential order. The sequence is roughly sequential, rather than precisely so, because learning of the components overlaps, rather than one process being mastered before learning of the next begins. For example, mapping a strategy from the original context in which it was learned to a new problem overlaps with strengthening the strategy so that it is used more often. Figure 2 does, however, provide a rough sense of the learning sequence, in that children must acquire a strategy in an initial context before mapping it to different problems, must know several strategies before refining their choices among them, and so on.

Data consistent with the overlapping waves model have been obtained across such varied tasks as serial recall, tic-tac-toe, arithmetic, time telling, spelling, reading, locomotor activity, rule learning, moral reasoning, and scientific experimentation (Adolph, 1997; Crowley & Siegler, 1999; Goldin-Meadow, Alibali, & Church, 1993; Granott, 1993; Karmiloff-Smith, 1979; Kuhn, Garcia-Mila, Zohar, & Andersen, 1995; McGilly & Siegler, 1990; Rittle-Johnson & Siegler, 1999; Schauble, 1990, 1996; Siegler, 1988; Siegler & McGilly, 1989; Thelen & Ulrich, 1991; Turiel & Davidson, 1986). In all of these areas, children have been found to use multiple strategies at any given age, with the variability existing within individual children as well as between children. In each area, children have been found to shift toward more advanced approaches with age and experience. The components summarized above also have been found to play important roles in preschoolers' and older children’s learning of a wide variety of tasks (Lemaire & Siegler, 1995; Siegler, 1995; Siegler & Chen, 1998; Siegler & Stern, 1998).

Moreover, computational models of strategy choice and strategy discovery have been formulated that generate patterns of change that closely resemble both the overlapping waves formulation and empirical data on children’s performance (Shrager & Siegler, 1998; Siegler & Shipley, 1995). These simulation models suggest that the overlapping waves pattern arises through a mix of strategy discovery and strategy choice processes. More
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specifically, the system’s problem-solving experience generates an increasingly extensive database regarding the properties of both strategies and problems. This database, together with the system’s basic architecture, makes possible discovery of new strategies, increased reliance on relatively advanced preexisting strategies, mapping of strategies onto novel problems, increasingly refined choices among strategies, and increasingly fast and accurate execution of strategies.

Overlapping waves theory also suggests a new agenda for studies of infants’ and toddlers’ cognition. Rather than trying to identify the age at which children develop a given competence or capability, we would trace over time the set of approaches that they use, paying attention to changing distributions of existing approaches as well as to the emergence of new approaches. We also would examine how emergence of a new approach changes choices among previous approaches. For example, we would try to learn whether use of the new approach comes completely at the expense of the least advanced existing approach, whether it comes proportionately from all of the existing approaches, or whether it comes primarily at the expense of the most advanced of the existing approaches (as would happen if both the new approach and the most advanced previous approach were used primarily on the most challenging problems in the domain). Finally, we would examine the circumstances surrounding discovery of new approaches. All of these goals can be addressed through the use of microgenetic methods.
Obtaining a precise understanding of cognitive change requires observing such changes while they are occurring. Traditional cross-sectional and longitudinal designs do not allow precise analyses of change, because the observations of intellectual competence are separated too far in time for much to be learned about the change process. This wide spacing of observations leaves open a large number of possible pathways to change. The problem is especially great because changes in children’s thinking often do not proceed by the most direct route imaginable. After discovering more advanced new approaches, children often temporarily abandon the new ways of thinking and regress to less sophisticated ones. This is true even when the children have stated compelling explanations for why the new approach is superior (Siegler & Jenkins, 1989). Exacerbating the problem, individual children often vary in their paths of change (e.g., Karmiloff-Smith, 1984; Piaget, 1971). A strategy that is transitional to a more advanced approach for some children may not be used at all by others (Kuhn et al., 1995; Schauble, 1996; Siegler & Stern, 1998).

Microgenetic methods offer a promising way to meet the challenges inherent in trying to understand change processes. The approach is defined by three characteristics: (a) an observation period spanning the time from the beginning of the period of rapid change to the stable use of target ways of thinking; (b) a high density of observations during this period, relative to the rate of change; and (c) intensive, trial-by-trial assessments of ongoing changes, both qualitative and quantitative. For recent perspectives on microgenetic methods and what they have taught us, see Kuhn (1995) and Miller and Coyle (1999).

A study conducted by Schauble (1996) illustrates how microgenetic methods can yield information about change that could not be attained using traditional cross-sectional or longitudinal designs. Fifth graders and adults were asked repeatedly over six sessions to generate experiments that would indicate the causal roles of each of four variables. Both the children and the adults increased their understanding of the impact of...
the variables through their experiments. The progress, however, was far from direct. Cases of learning rarely involved children or adults progressing from an incorrect understanding of a variable to a correct understanding and then maintaining that correct understanding. Instead, more than 80% of belief revisions involved at least three changes back and forth, and some involved as many as eight. Both adults and 11-year-olds frequently returned to incorrect beliefs that they had earlier explicitly rejected on the basis of contrary evidence, though adults did so somewhat less often. Without the trial-by-trial analyses afforded by the microgenetic method, such regressions and jagged paths of change would not have been detected.

Microgenetic methods have proved useful for studying a wide range of age groups, content domains, and issues. They have been used to study cognitive change in preschoolers (e.g., Siegler & Jenkins, 1989), school-age children (e.g., Coyle & Bjorklund, 1997), adolescents and college students (Kuhn et al., 1995), and elderly adults (Siegler & Lemaire, 1997). They have been used to study change in domains as diverse as attention (Miller & Aloise-Young, 1996), memory (Bjorklund, Coyle, & Gaultney, 1992), arithmetic computation (Siegler & Jenkins, 1989), mathematical principles (Alibali & Goldin-Meadow, 1993), conceptual understanding (Metz, 1998), social problem solving (Wertsch & Hickmann, 1987), scientific reasoning (Kuhn et al., 1995; Schauble, 1996), pictorial representation (Karmiloff-Smith, 1986, 1992), and analogical reasoning (Chen & Klahr, 1999). Among the issues that they have allowed researchers to study are developmental differences in learning (Coyle & Bjorklund, 1997; Kuhn et al., 1995; Metz, 1998; Schauble, 1996) and the relation between initial knowledge and the acquisition of new knowledge (Alibali, 1999; Staszewski, 1988).

Microgenetic methods have proven particularly useful for studying individual differences. The reason is the large amount of data they yield about each child’s learning. They allow us to identify differences in the types of strategies that children use initially, in the benefits they derive from various types of experiences, and in the path of change that their thinking follows.

Microgenetic studies also have suggested a useful conceptual distinction for thinking about individual differences in cognitive change. The distinction is between distal and proximal influences on change (Siegler & Chen, 1998). Distal influences are characteristics that children bring with them to the experiment: age, sex, IQ, content knowledge, and so on. Proximal influences are processes that children execute in the course of the experiment, such as the five components in Figure 2. Many analyses of individual differences in older children and adults have linked variation in distal variables to variation in learning outcomes. For example,
older children, children with higher IQs, and children with greater initial knowledge all tend to learn more from relevant experience (Coyle & Bjorklund, 1997; Johnson & Mervis, 1994; Schneider, Korkel, & Weinert, 1989). These distal influences, however, presumably exercise their influence by affecting the proximal processes that occur during the course of the experiment. For example, children with greater initial content knowledge may learn more quickly and completely because they more accurately encode stimulus displays, better recall information from prior trials, generate higher quality analogies to comparable past situations, and so on. These proximal processes directly produce learning in the experimental situation. In microgenetic studies with older children, successful execution of proximal processes that occur earlier in the learning sequence has been found to exercise large influences on success in executing subsequent processes (Rittle-Johnson, 1999; Siegler & Chen, 1998). Usually, the immediately preceding proximal component exerts the largest influence. Distal influences, however, can and fairly often do exert an additional influence, above and beyond that of the proximal processes.

Microgenetic methods have been adopted by researchers with a variety of theoretical perspectives: Piagetian (Inhelder et al., 1976), Vygotskian (Wertsch & Hickmann, 1987), dynamical systems (Thelen & Ulrich, 1991), and information processing (Bjorklund & Coyle, 1995). Despite the investigators’ varying theoretical predispositions and the diverse content domains to which microgenetic methods have been applied, the descriptions of change that have emerged from the studies are strikingly similar. One consistent finding was cited earlier—that discovery of new strategies is conceptually constrained. Another consistent finding is that cognitive change tends to be gradual. Older, less powerful ways of thinking about a task usually continue to be employed for a long time after newer, more advanced ways of thinking about it are also available (Kuhn, 1995; Metz, 1985; Schauble, 1990, 1996; Siegler, 1994). A third consistent phenomenon that has emerged from microgenetic studies is that discoveries are made when children have been succeeding on the task as well as when they have been failing (Karmiloff-Smith, 1992; Miller & Aloise-Young, 1996; Siegler & Jenkins, 1989). Necessity can be the mother of invention, but new ideas also emerge without any external pressure. Yet a fourth consistent finding is consistent positive relations between the initial variability of thinking and the subsequent rate of learning. In many, but not all studies, the greater the initial variability, the more likely that children will generate useful new problem-solving strategies (Alibali & Goldin-Meadow, 1993; Goldin-Meadow, Alibali, & Church, 1993; Graham & Perry, 1993; Siegler, 1995).

These consistent phenomena, in turn, have given rise to a set of intriguing proposals regarding the processes that produce the changes. To
account for the persistent use of nonoptimal strategies, despite more effective strategies being known, the construct of utilization deficiency has been proposed (Bjorklund & Coyle, 1995; Miller & Seier, 1994). To account for why discoveries occur when existing strategies are producing successful performance, the SCADS computer simulation progressively frees cognitive resources as it gains experience executing existing strategies, thus making possible construction of effective new strategies (Shrager & Siegler, 1998). To account for positive relations between initial variability and subsequent learning, investigators have focused on the ways in which variable behavior reveals the possibilities inherent in the task environment, which often leads to discovery of useful new approaches (Neuringer, 1993; Stokes, 1995).

Although microgenetic approaches have become an increasingly important approach in examining older children’s cognition, they rarely have been used to study infants’ or toddlers’ thinking. Perhaps the most important reason was alluded to earlier: The questions that have been dominant in the area have given little incentive to those studying infants’ and toddlers’ thinking to use microgenetic methods. A second important reason involves the logistics of doing research with infants and toddlers. Children of these ages have relatively short attention spans and lack the verbal facility to explain their reasoning. Studying their thinking microgenetically would require relatively short sessions and use of nonverbal methods to assess strategy use.

Fortunately, these considerations in no way preclude use of microgenetic techniques with infants and toddlers. Although such young children cannot generate verbal reports, they do generate a great deal of overt behavior that can be at least as useful for inferring strategy use on a trial-by-trial basis. With well-chosen tasks and age groups, trial-by-trial analyses can reveal a considerable amount of change within a relatively short session or series of sessions. Most important, the inherent importance of change in the lives of infants and toddlers means that we must understand it better if we are ever to have a comprehensive understanding of children’s thinking. Indeed, the omnipresence and rapidity of change during the first years of life suggest that using microgenetic methods to study very young children could lead to especially great advances in understanding.

One of the very few microgenetic studies of infants illustrates the type of advances that this method can yield. The study (Adolph, 1997) examined how infants and toddlers learn to locomote up and down ramps of varying slopes. Adolph followed the infants at frequent intervals from the time when crawling was their predominant mode of locomotion on flat surfaces to the time when walking had become dominant. The research indicated that the infants and toddlers used a variety of strategies for going up and down the ramps: crawling, walking, sliding on their
bellies, sliding on their behinds, and so on. Adolph also found that the infants and toddlers adjusted their locomotor strategies to the demands of the tasks. They used their predominant mode of locomotion on relatively shallow slopes, but when they needed to descend down steeper slopes, they relied more often on safer strategies, such as sliding down feet first. She also found that the precision of infants’ choices reached quite high levels by the end of the period in which crawling was their predominant mode of locomotion, but that it regressed substantially when walking became their predominant mode. Although Adolph conceptualized her findings within a motor development framework, the study also suggests that microgenetic methods can be used to study infants’ and toddlers’ acquisition of problem-solving skills.