The Development of Problem Solving in Young Children: A Critical Cognitive Skill

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Abstract

Problem solving is a signature attribute of adult humans, but we need to understand how this develops in children. Tool use is proposed as an ideal way to study problem solving in children less than 3 years of age because overt manual action can reveal how the child plans to achieve a goal. Motor errors are as informative as successful actions. Research is reviewed on intentional actions, beginning with block play and progressing to picking up a spoon in different orientations, and finally retrieving objects with rakes and from inside tubes. Behavioral and kinematic measures of motor action are combined to show different facets of skill acquisition and mastery. We need to design environments that encourage and enhance problem solving from a young age. One goal of this review is to excite interest and spur new research on the beginnings of problem solving and its elaboration during development.

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INTRODUCTION

One could argue that the continuance of our species on earth depends on whether we solve the global problems that face us. A critical aspect of this problem solving is how far into the future can we plan prospectively. Can we predict the steps and take the actions to lessen global warming, to prevent the collapse of the environment, and to preserve endangered species? While these are a few of the grave problems that scientists, governments, and indeed all citizens face, the developmental psychologist asks a different question: When does the developing human become capable of problem solving, and how does it develop? The answer may surprise you: Planning ahead in order to achieve a goal is solidly present during the second year of life, with the earliest inkling of this process beginning in the first year. Despite a long history reaching back to Kohler's apes (1927) and Piaget's work with human infants (1952), developmental psychologists' attention to problem solving has been one of spirited starts followed by benign neglect. In the space allowed this article, I cannot review the large literature on problem solving in developmental psychology. I highlight three classic articles and then review my own work and related articles in detail.

TOOL USE: A ROYAL ROAD TO THE STUDY OF PROBLEM SOLVING

Seminal, thought-provoking articles on problem solving have appeared about once every decade since the 1970s, beginning with Bruner's article in *Child Development* (1973). In this still-relevant article, Bruner laid out a plan for the development of skilled action. First there is intention, then an assembling of "constituent acts," which initially occur out of order but later become properly sequenced to reach the goal. Bruner emphasized the role of exploratory behavior and play prior to achieving skilled action. Flexibility and higher order acts become possible through reorganization of component acts and modularization. Although Bruner's examples came from infants in the first year of life, his ideas for how problem solving progresses can be applied to acquisition of more complex skills beyond infancy.

About a decade later, Elizabeth Bates and colleagues (1980) explored the role of perceptual factors that enabled 9- to 10-month-olds to solve a tool use problem. Kohler (1927) maintained that proximity between tool and object was essential for the animal to make the connection and use the tool. Bates et al. (1980) manipulated color, texture, spatial arrangement, and type of contact between tool and desired object. This pioneering study used a series of tool-object arrangements, graded in difficulty. They found that infants' insight into how to use a tool depended on spatial contact rather than making tool and goal object more perceptually similar. While emphasizing the importance of tool use and problem solving, these authors pointed out that we do not understand the processes that underlie these activities; this was true in 1980 and is still true today.

In 1990, Ann Brown tackled the difficult issues of how children learn and transfer knowledge, thereby producing one of the most frequently cited articles in the developmental problem-solving literature. She argued against earlier views that young children learn on the basis of associating highly similar or identical elements across problems. She claimed that children have knowledge of "deep structural principles" that can override surface similarities. Furthermore, if the child has adequate understanding of the problem's causal structure, transfer will occur. Such knowledge, however, is not acquired in an all-or-none fashion. For example, at 10 months the infant appears to know that physical contact between a string and a toy is necessary. The 14-month-old appears to know that length, rigidity, and type of head are critical for using a rake or hook to pull an object toward one, and will select the appropriate tool from an array of possible tools. But this knowledge may not transfer to a problem where point of contact is not visually available, such as a rake with a toy adjacent but not touching. Not until around 24 months of age can the child combine the knowledge about the necessity for physical contact with appropriate properties of the rake tool. Infants younger than 24 months have difficulty imagining the contact, then manipulating the appropriate tool to bring it about. Brown used her own ingenious studies combined with those of Bates et al. (1980) to illustrate that having knowledge of causal mechanisms does not guarantee being able to use it to solve problems. Demonstrations from adults and environmental support (e.g., providing physical contact between tool and object to be manipulated) can enable children to find a solution before they are able to imagine it themselves.

All of the articles just mentioned used some form of tool use as a way to study the genesis of problem solving. Although these articles are oft-cited classics, the topic of tool use has never taken center stage in developmental psychology. Bruner, Bates, and Brown all did significant research into the problems they were theorizing about, but others did not pick up the standard and give it the attention it deserves. This may be changing. Relating the study of tool use to its place in our evolution, Smitsman (1997) said, "It is therefore remarkable that tool use was rarely studied by developmentalists" (p. 301). Two publications in 2000 stressed the continuity between infants' early interest in objects, which has received a great deal of research, and later tool use. In contrasting babies' manipulation of toys versus tools, Gibson & Pick (2000, pp. 98–99) noted that toys offer the infant opportunities to explore surfaces, textures, and sound-making potential whereas tool use demands planning of sequential acts that lead to a goal. Lockman (2000), in his influential article on tool use development, likewise noted that infants' early interest in and exploration of objects is a precursor of later tool use. Their initial manipulation of objects leads to using them later to accomplish a goal. An example is a 9-month-old banging a spoon for the sake of making a noise and engaging in rhythmic activity. Only later is the spoon viewed as a means of conveying food to the mouth. Lockman, Gibson, and Pick all agree that tool use emerges gradually, growing out of infants' exploration of object-to-object relations. One purpose of this article is to give the study of tool use another boost. Perception, motor skills, and cognition come together in a rich stew in tool use studies of problem solving. Early in my career I was taught and I believed that the best strategy for understanding development came from concentrating on these processes separately (Clifton 2002). The so-called whole child approach would lead nowhere. Now I believe that perception, cognition, and motor development are so intertwined and related that it is usually unwise to study a single process in isolation. As Bates et al. (1980) pointed out, even language and attachment are related to problem solving.

The second purpose of this article is to review my own work on problem solving and closely related literature. My studies of

Tool use: using an object to act on the environment to accomplish a goal. Tool use implies means-end behavior, that is, using one object (means) to achieve a goal (end)

Kinematic measures: attributes of a limb's motion (e.g., hand, arm) through space such as velocity, acceleration, deceleration, etc.

problem solving, particularly those of tool use, involve at least a two-stage process whose solution is not obvious from the perceptual features of a display. These problems always involve finding a motor solution to a cognitive problem. The advantage of studying this type of problem is that one can design a study so that the child's overt behavior makes interpreting the underlying cognitive processes more transparent. Because verbal responses are either impossible or unreliable in infants and children under three years, the readily observable and recordable behaviors like reaching and grasping offer valuable insights to the child's reasoning and understanding of the problem. Children's intentions are expressed through the particular form an action takes (e.g., type of grip on an object) or the skill with which an action is accomplished (e.g., its speed and precision). Close attention should be paid to motor errors, as they can reveal intentions gone awry. Kinematic measures as well as overt behavioral responses will be used to infer how the child was conceptualizing the problem and how mental imagery of objects and actions may have been used. I begin by describing studies of prospective planning and intentional behavior, followed by studies of tool use in infants and preschoolers.

PROSPECTIVE CONTROL OVER ONGOING ACTIVITY VERSUS PLANNING FUTURE ACTION

Because very young infants display prospective planning in their motor behavior, a clear distinction needs to be made between this process and problem solving, to be covered later in this review. Object properties such as size (Newell et al. 1989, von Hofsten & Ronnqvist 1988) and orientation (Lockman et al. 1984, von Hofsten & Fazel-Zandy 1984) elicit preparatory sizing of grip and adjustments in hand orientation in infants less than one year of age. In these studies, properties of the object, its location, and its orientation in space were always visible to the infant, so representation was not necessary for prospective planning. Other studies provide strong hints that infants less than one year old might be using mental imagery. Clifton et al. (1991) presented small (which elicited a one-handed grasp) and large (which elicited two-handed grasps) objects in the dark and found that 6-month-olds chose the appropriate grip configuration for the object's size. Prior to trials in the dark, the large and small objects were presented in the light, and each object had a unique sound that could identify the object when heard in the dark. We concluded that infants were responding to size of the unseen objects on the basis of mental representation, a radical claim for 6-month-olds. McCarty et al. (2001a) presented rods oriented vertically or horizontally out of the infant's reach, then turned out the room lights before bringing the rods within reach of 9-month-olds. A sound was emitted from the center of the rod to specify its movement forward to within reach, but the sound was the same for both positions, so offered no clue to the rod's orientation. Infants showed appropriate hand orientation for these unseen rods, similar to that when the rods were visible. In both of these studies, infants presumably made motor adjustments based on memory for sight of the object some moments earlier.

Moving objects offer another example. Von Hofsten (1980) presented a moving toy whose trajectory brought it within reach of infants, who were able to reach out and grasp it. Von Hofsten argued that infants anticipated the future point in space where the hand had to be aimed to intercept the object. Finally, kinematic measures as well as gross motor behaviors indicate that infants may be using mental imagery when reaching for unseen objects. Clifton et al. (1994) presented sounding objects in the dark while recording kinematic measures and reported that infants' hands decelerated before contact with the unseen object, just as they did in the light when reaching for visible objects. Infants in this study were only 7 months old, and these data suggest that they had some imagery of the object's location. All of these studies are strongly suggestive but by no means conclusive about whether infants under one year of age may have mental imagery about upcoming events.

The problem solving covered in this review cannot be based on visible perceptual properties of objects or memory of a fleeting image of the object's location or orientation. The solution to these problems requires a two-stage process that involves planning for future actions, first when reaching for a toy or tool and then using the object to achieve a goal after it is in the hand. The goal is not visible in the array, but must be constructed by the child from information in the situation. In this sense, the child moves beyond prospective control and begins to plan multistep future actions.

I begin by describing two studies of goal-directed behavior that featured the same object in the performance of two different actions. One action was casual, a grasp of an object and release into a wide, open container. The other was precise, as after the grasp the object was inserted into a tight-fitting opening or balanced on top of a tower. The idea of contrasting reach and grasp of an object when the person performed subsequent divergent actions came from the adult literature. When adults reach for an object, the kinematics of that movement forecast what the person intends to do with it once the object is in hand. Johnson-Frey et al. (2004) found that approach kinematics was affected by the adult's intention to transport the object to a new location, versus simply lifting and holding it. Likewise, Marteniuk et al. (1987) found that if the subsequent action requires precise perceptual motor action such as placing the object into a tight-fitting hole as opposed to releasing it into an open container, then the hand's approach is slower, has lower peak speed, and has a longer deceleration as the hand approaches the object. This same kinematic pattern of approach to picking up an object is seen when adults are asked to pick up a small object (e.g., a matchstick mounted upright) compared to a larger object (Berthier et al. 1996). In Berthier et al.'s study, the task is truly more difficult because small objects require very precise sizing of the aperture between thumb and index finger, but in Marteniuk et al.'s study, adults were reaching for the *same* object. There is no apparent advantage for the approach movement to reflect their future intentions, yet adults unwittingly betray their future action plans for the object. I say "unwittingly" because adults seem unaware of the kinematic differences in their movements under these two conditions.

Do infants engage in two-step motor planning similar to adults? By presenting the same object (a ball) and encouraging the infant to sometimes throw it down and sometimes fit it into a hole, we might observe kinematic differences that forecast infants' upcoming action. If infants reached similarly on all trials, we would conclude that the ball's visible properties of size and shape determined the reach, rather than plans for future movement. Ten-month-olds were tested because infants younger than this have trouble with the throwing motion. Both peak and average speed of the approach for the ball were lower when the subsequent action was precise compared to imprecise (Claxton et al. 2003). We concluded that infants are capable of planning two-stage actions, shown by the first stage being affected by the upcoming action of the second stage. Past research has shown that infants are responsive to perceptual properties of the object, but the Claxton et al. (2003) data indicated cognitive factors also influenced planning of the reach-to-grasp movement. The infant is looking beyond what is visually present and considers future actions with the object about to be grasped. Although this motor adjustment might also be called prospective control, I see it as a bridge to future problem solving because it depends on some representation beyond what can be perceived in the environment.

STRUCTURING SEQUENTIAL ACTIONS TO ACHIEVE A GOAL: BUILDING A BLOCK TOWER

When parents watch infants—especially toddlers in the second year of life—at play, they see more complicated acts than the ones just described. Toddlers engage in sequential acts that build on past actions. For example, they will complete a simple puzzle, the kind where each piece has its own separate indentation to

Point of peak velocity (PPV): the proportion of a reaching movement where peak velocity occurred; for example, a PPV of 0.5 means the fastest speed was reached halfway through the movement

Peak velocity: the fastest speed at which the hand moved when making a reach for an object

match its shape. Around 18–24 months of age, they will build block towers (**Figure 1**). At first they are capable of balancing only two or three blocks, but soon the tower rises to four, five, and beyond, into a tall tower. They show this to the parent with pride. What lies behind this skill and why is it important? To build a tall tower, children must have a plan that requires many sequential movements of picking up and stacking blocks in a precise arrangement. In addition, they must have the requisite motor skill to release successive blocks onto the tower without making it topple. Parents should be impressed with both the child's cognitive planning and motor skill when they see this accomplishment. They might also wonder if a child who shows this skill very early might have special fine motor aptitude.

We conducted a study in our lab that asked whether the motor skills of high- versus low-tower builders would show up in kinematic measures of their movements (Chen et al. 2010). Would high-tower builders' speed profile in approaching the tower and releasing the blocks be different? If so, would their movement characteristics be different from low-tower builders if retested a year later? The answer to both of these questions is "yes," but there were surprises.

Toddlers between 18 and 21 months of age were tested because the Bayley Scales of Infant Development (Bayley 1969) includes this age range as the period when some but not all children become able to build tall towers. The average tower that a 17-month-old can build is around three blocks, and by 23 months the average height is six blocks. By testing in the 18- to 21-month range we expected that some children would build low towers (defined in our study as two- to three-block towers), and some would build high towers (defined as four or more blocks in the tower). We presented the children with two tasks: the precision task being tower building, and the more casual, imprecise task being to "clean up" the blocks by placing them all into a wide, open container. The kinematic measure that proved most sensitive to motor skill differences was PPV, or point of peak velocity. This telling measure specifies where in the movement the hand reached its fastest speed. For movements that require high precision at the very end of the movement (in our case, releasing the block on top of the stack), peak speed should be reached early in the movement, as this allows ample time for the hand to decelerate and be finely controlled at the moment when greatest precision is needed. Children building high towers reached peak speed earlier in their movements, about a quarter of the way into the reach (28%), compared to the low-tower group, whose peak was reached around 36%. **Figure 2** shows a single trial for a child in each group, and the long deceleration of the high-tower child's hand as it approaches the tower in anticipation of placement is apparent. Peak velocity was reached very early, only 0.15 proportion of the total reach. This pattern of reaching peak velocity early in the movement is typical for adults performing precision tasks (Berthier et al. 1996, Johnson-Frey et al. 2004).

A subset of these children (all we could locate after a year had gone by) was retested on the same tasks when the children were close to 3 years of age (Chen et al. 2010). We reasoned that if the high-tower group's better performance in tower building shown at 18–21 months reflected a stable talent for fine motor skills, then kinematic differences should persist between the groups. On the other hand, if the high-tower group consisted of children who, for whatever reason, happened to achieve skill in building block towers earlier than average, then kinematic differences should disappear a year later, when all children can easily build tall block towers.

The kinematics of the two groups were significantly different a year later, but they had flipped. The high-tower children now had a shorter movement time, reached peak speed later, and were going faster when they released the block onto the stack. These characteristics show fast, skilled movements to complete a tower. Perhaps the task had become boring for this group. Our interpretation of this change in pattern was that high-tower children when tested first at 18–21 months were in an early stage of mastering this new skill. Going slowly as they approached the tower, block in hand, was associated with more success in keeping the stack intact. A year later, when all children are capable of building towers of seven to eight blocks, these high-tower children have mastered this task, and they show it by going faster. It is important to note that the high-tower group did not move faster in general; there was no difference between groups when they were asked to place all the blocks into the open container. Their superior motor skill was only apparent in the kinematics of the precision task.

Many interesting questions emerge from this study. We do not know what led to the high-tower group's greater skill in fine motor control. How much innate differences might have contributed or how the environment fostered the children's ability is unknown. We do know that precocity needs the proper environment in early life for its expression, regardless of innate talent. Imagine Mozart without a keyboard and Tiger Woods with no golf club throughout childhood. What the Chen et al. (2010) study does show is that advanced development of early motor skills can show up in the second year of life, can be successfully measured through both kinematics and overt behavior, and can persist at least for one year into the preschool period.

EVOLUTION OF AN ACTION PLAN: GRASPING THE HANDLE OF A TOOL

Building block towers does not require a tool, but it shares certain cognitive abilities with tool use, namely planning sequential actions, anticipating the effects of these actions, and having a clear goal structure. The use of tools lends itself well to the study of problem solving because children must engage in planning that reveals hierarchical organization in their thinking. Friedman & Scholnick (1997) laid out a task analysis that incorporates several aspects of Bruner's (1973) more fluid ideas. They describe the sequence as first representing the problem, followed by devising and carrying out a solution, monitoring its effectiveness, and finally making corrections. This schema fits well with the behaviors of infants learning to pick up a spoon, to be described in the next section.

The study of how children learn to use spoons as eating utensils has a long history, reviewed by van Roon et al. (2003). Connolly & Dalgleish (1989) detailed the stages and components of learning to self-feed. This work influenced our choice of age range and task, but our purpose was quite different. Our research was inspired more by Rosenbaum and colleagues (Rosenbaum et al. 1990, 1996, 2006) than by the desire to learn more about self-feeding. We wanted to use the activity of picking up a spoon to study problem solving and planning in infants. The situation we used was simple: offer a spoon whose bowl has been loaded with food, a task that our youngest participants at 9 months of age understood. The length of the spoon was presented horizontally to the body so that the handle pointed either left or right. We did not worry about individual hand preference because the handle alternated equally often to each side, making half the trials easy and half difficult for each child. The "easy" orientation was for the handle to point toward the child's preferred hand, usually the right for most of the population. Why easy? Even a 9-month-old baby whose facility with spoons is minimal will pick up the spoon with an overhand grip on the handle, thumb toward the bowl end of the spoon in the correct radial grip, and successfully convey food to the mouth (Connolly & Dalgleish 1989, McCarty et al. 1999). The difficult orientation was the handle pointing toward the nonpreferred hand, generally the left. Even though hand preference is unstable at 9 months, we observed the following scenario. The infant persists in primarily using a preferred hand to pick up the spoon, resulting in an ulnar or bowl-end grip when the spoon is in the difficult orientation. Result? The end of the handle goes into the mouth! The infant soon realizes no food is forthcoming, and after several manipulations finally gets some of the food into the

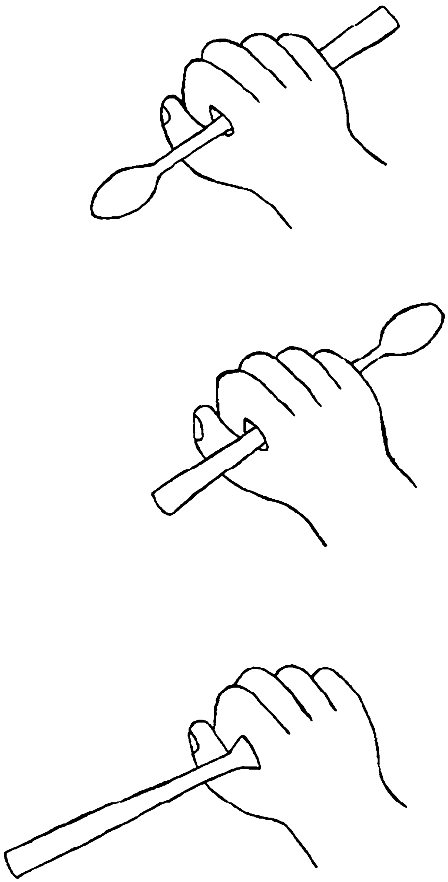

Figure 3

Schematic drawing of three grips on a spoon. The top drawing shows the correct radial grip, the middle drawing shows an ulnar grip, and the bottom shows the bowl-end grip. (Modified from McCarty et al. 1999, Problem solving in infancy: the emergence of an action plan, *Dev. Psychol.* 35:1094. Copyright 1999 by the American Psychological Association. Reprinted with permission.)

Radial grip: the hand encloses a tool's handle with the thumb toward the action end of the tool (e.g., bowl of spoon, head of hammer)

Ulnar grip: the hand encloses a tool's handle with the little finger on the action side of the tool (e.g., the bowl of the spoon sticks out from the ulnar side of the hand)

mouth. The 9-month-old's choice of a grip on the spoon indicates that he/she is not planning ahead. **Figure 3** shows three possible grips on the spoon by infants. The bowl-end grip and the ulnar grip indicate lack of planning; only the radial grip shown at the top of the figure is correct and most efficient.

By using this simple situation of offering food on a spoon with the handle oriented in different directions, we were able to study problem solving over a wide age range of children less than two years of age. Although every child was motivated to get the food, was able to pick up the spoon, and eventually got to eat the food, there were numerous ways of achieving this goal. The route to success revealed the point at which children realized there was a problem with their grip, and the correction of errors indicated their evaluation of the problem. **Figure 4** is a schematic diagram of changes in strategy between 9 and 19 months of age. The most primitive strategy, termed "feedback-based strategy" by McCarty et al. (1999), results in the ulnar or bowl-end grip shown in **Figure 3**. Only when the expected food fails to arrive in the mouth does the 9-month-old appear to recognize the mistaken grip and correct it. The second stage, "partially planned strategy," is perhaps the most interesting. In this stage, which was most typical of our 14-month-old group, the child picked up the spoon in both orientations with the preferred hand, but on the way to the mouth realized there was a problem if the spoon had been seized in an ulnar grip. Solutions were many. Sometimes the child laid the spoon down on the table, twirled it until the handle pointed toward the preferred hand, then proceeded to pick it up again with that hand. Sometimes the child transferred the spoon to the nonpreferred hand, resulting in a radial grip for transport to the mouth. And sometimes the child maintained the ulnar grip in the preferred hand but twisted hand and arm to get the food into the mouth (**Figure 5**). We called this the awkward grip, and it was a frequent solution for children in this age group because they do want to use their preferred hand every time, even though the twist of arm/hand cannot feel very comfortable.

Adults are quite good at assessing how a grip on an object will result in a future awkward posture, and they avoid it. Rosenbaum et al. (1990) have termed this the desire for end state comfort. That is, adults choose a hand or a grip that may be awkward initially but at the goal state will be comfortable. At 14 months, infants either do not mind the awkward end state of their arm and hand, or they are dead-set on

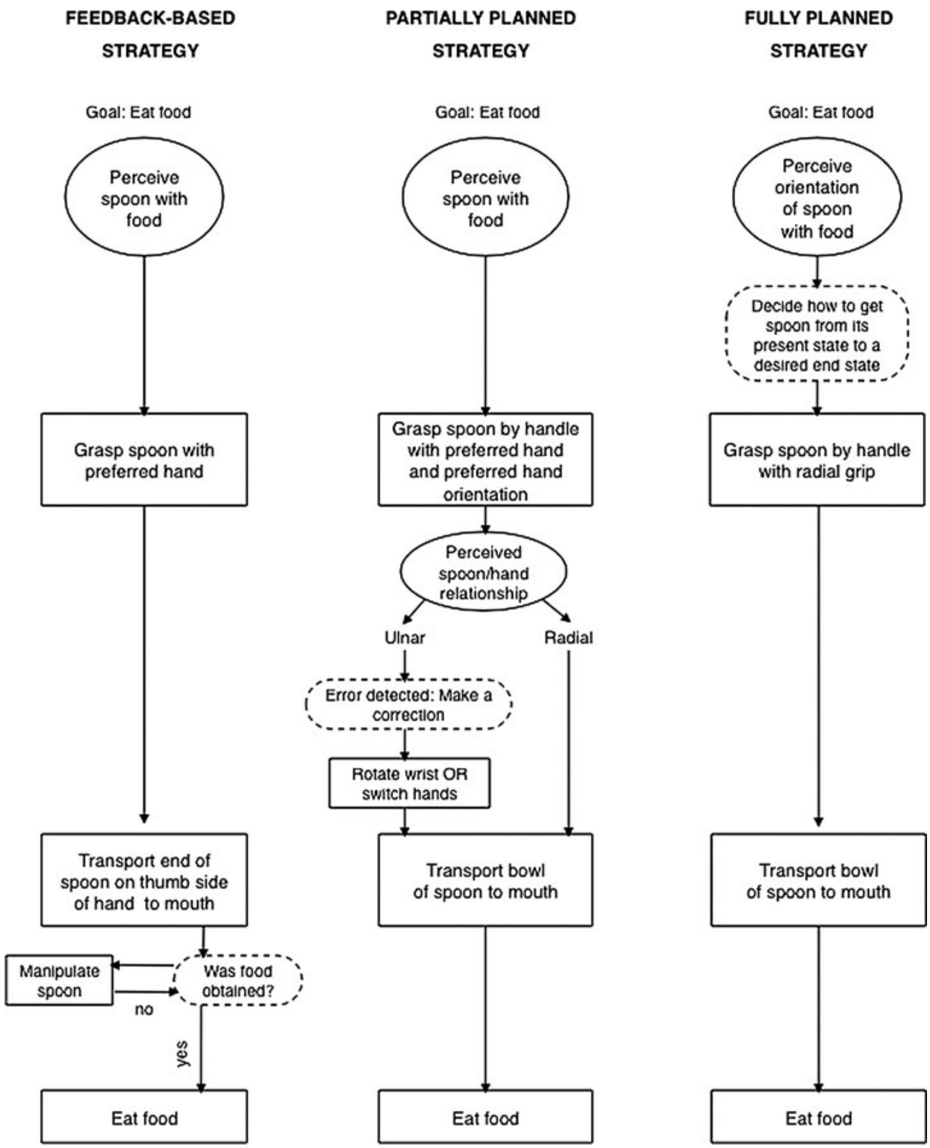

Figure 4

A diagram of three strategies used by children learning to pick up a spoon. Circles represent perception, solid boxes represent action, and dashed boxes represent thought processes. (Modified from McCarty et al. 1999, Problem solving in infancy: the emergence of an action plan, *Dev. Psychol.* 35:1110. Copyright 1999 by the American Psychological Association. Reprinted with permission.)

using their preferred hand and will put up with the awkward end state. Two studies have tested children between 2.5 and 6 years of age and found that throughout this period, children do not plan grips that will end in a comfortable hand position (Adalbjornsson et al. 2008, Manoel & Moreira 2005). The former study had children pick up an overturned glass and position it upright. Children were found to use a wide variety of hand manipulations to accomplish this, although the end state comfort solution was observed infrequently. The latter study manipulated precision to see if more difficulty resulted in more planning for end state comfort, as it does in adults.

At 19 months of age, children executed a fully planned strategy, as detailed in **Figure 4**. They noticed the handle's orientation and used it to guide their selection of which hand to extend and grasp the handle (McCarty et al. 1999). They appeared to know in advance that the radial grip is the most efficient and comfortable, so as the spoon's handle alternated to the left and the right, they alternated their choice of hand. In this way, these 19-month-olds achieved radial grips on every trial, abandoning the preferred hand's awkward grip in favor of end state comfort with the nonpreferred hand. Does our finding of toddlers' ability to plan for end state comfort conflict with the studies of preschoolers that find they do not? Manoel & Moreira's (2005) study used a task similar to that of Rosenbaum et al. (1990). Children were asked to pick up a bar whose ends were painted different colors (red or green) and then place a specified end into a hole in a box. Translating this task to our spoon situation, the easy orientation would allow the children's preferred grip, a right overhand grip on the middle section of the bar, or a left underhand grip. The difficult orientation would be a left overhand grip or a right underhand grip to achieve the thumb-toward-action-end that results in end state comfort. Their results show a strong tendency to use the right overhand grip, regardless of which end was to go into the hole. Simply said, these children, aged 2.7 to 5.9 years, were loath to give up their preferred grip, even when it resulted in a less comfortable end state posture. No age trends were found in this study, although the number tested at each of seven age groups was very small (Ns = 5 or 6). It may be that toddlers under 2 years of age in our spoon situation were more willing to use the left hand because handedness is still in fluctuation, allowing environmental circumstances to drive the use of the nonpreferred hand. As handedness stabilizes in later preschool years, children may become more insistent on using the preferred hand even when it is less advantageous. More research is needed to establish when the adult pattern emerges.

As toddlers approach the end of the second year of life, they adjust their grip to changes in a spoon's orientation, but this does not extend to other items with handles. In addition to the spoon, McCarty et al. (1999) presented a variety of toys with handles (bell, rattle, etc.). The developmental trend toward more radial grips was only seen when toddlers reached for a spoon, and not when they reached for toys. This difference suggests that toddlers think about what they are going to do with the object when planning a reach. The grip on a spoon's handle was followed by eating food, whereas picking up a toy was followed by more indefinite goals, such as visual examination or further manipulation. These activities do not suffer from an ulnar grip, unlike the spoon, where food can spill as the wrist rotates. Perhaps thinking about the consequences of the grip propelled the toddlers to plan ahead for a radial grip on the spoon. We are reminded of the Claxton et al. (2003) finding that 10-month-olds appeared to be thinking ahead about a precision action versus a throwing action when reaching for a ball. In that case, the kinematics of the reach differed with the upcoming action, and in the spoon's case, the toddlers' plan for gripping the spoon's handle was possibly affected by the gustatory consequences of the action, but this would not be the case for toys.

The difference in grips on toys versus spoons was intriguing, but no definitive reason could be advanced in the 1999 paper. Several differences between these objects could have led to the finding. The indefinite goal of toys has already been mentioned, but other possible reasons include the greater familiarity of the spoon and that its action was directed toward the self. Hand-to-mouth actions are among the earliest movements seen in infants, and by 9 months (the youngest age tested on the spoon task), all infants have had tremendous practice in bringing objects to the mouth. In McCarty et al. (2001b), we compared use of radial grips on tools that had a definite purpose (hammer, magnet, hairbrush, and spoon). The hammer and magnet acted on other objects, and the familiar spoon and less familiar hairbrush could be self-directed or other-directed toward a stuffed lion puppet. We hoped to separate object familiarity from the direction of the object's action by comparing radial grips for these different tasks.

The results were quite clear-cut. Self-directed actions led to more radial grips, with both spoon and hairbrush. When these same tools were other-directed toward the puppet (the instructions were "Feed the lion" and "Brush the lion"), radial grips were fewer and not significantly different from the hammer and magnet. In this study, four age groups were tested: 9, 14, 19, and 24 months. Again, a strong age trend emerged, with the three older groups using more radial grips than the youngest. By 19 months, about 75% of self-directed trials featured radial grips, and by 24 months this had climbed to over 80%. Thus, by 2 years of age, children were assessing the orientation of spoon and hairbrush and then planning their grip accordingly on the great majority of trials. This impressive feat of future-oriented action only occurred in the context of self-directed actions and included actions with the less familiar hairbrush as well as the ubiquitous spoon.

But wait! I hear you say. Aren't you forgetting that other-directed actions had no clear negative or positive consequences? If the child missed the pounding pegs with the hammer or failed to pick up a metal object with the magnet, there was no obvious negative consequence. The self-directed spoon results in food in the mouth and the hairbrush generates a gentle sensation on the scalp. There is no similar feedback from brushing and feeding the lion. What if there was a visible consequence, positive and negative, for radial versus ulnar grips on the handle of a tool that was other-directed? We devised a waterwheel task in which a dipper was prefilled with water before it was presented to the child (Claxton et al. 2009). A radial grip allowed the child to pour the water on a wheel, causing it to spin, which delighted most of the children. An ulnar grip resulted in spilled water as the child attempted to pour water on the wheel. Every child experienced both spoon and dipper trials, with the handle pointing right and left equally often. We tested only 19-month-olds, an age at which our previous studies had shown that children typically employed radial grips on the spoon. A high percentage of radial grips was found for both tools, but the self-directed action of the spoon elicited more radial grips than the dipper filled with water (93% for the spoon and 79% for the dipper). In the waterwheel task, goal salience was enhanced, and errors in grip produced visible results; still the self-other difference in planning the correct action remained. In infancy, self-directed actions (e.g., thumb-sucking, putting objects into the mouth) are seen before other-directed actions (e.g., banging, putting one object into another). Toward the end of the second year of life, self-directed actions are still privileged in that planning the most efficient grip on an object is easier when the action of the object will come back toward the body.

Koslowski & Bruner (1972) researched problem solving with a lever task that in many ways is analogous to the spoon problem. Infants 12 to 24 months of age sat at a table with a sort of lazy Susan device. A toy was placed on a bar that could be rotated 180° to bring the toy within reach. Most children tried several strategies, with the oldest succeeding the best. In the discussion, the authors analyzed skill learning into steps that can also be applied to the spoon problem. Their first general principle is that "development consists of successive levels of organization of components" (p. 796). This implies that in a problem-solving situation, the child may have all the components, but they are not organized into a sequence that will result in success. For example, the visual array may be accurately assessed but elicit an incorrect prepotent response. In the case of the rotary lever problem, if the child attempted a direct reach for the toy or pulled the lever toward themselves, neither action succeeded. In the case of the spoon problem, the prepotent response is to pick up the handle of the spoon with the preferred hand (usually the right). In the spoon's difficult orientation, this leads to limited success—food goes into the mouth—but has a cost, namely, the hand and wrist are twisted in an awkward grip (see **Figure 5**).

This last situation leads to Koslowski & Bruner's (1972) second general principle in the development of problem solving that deals with how and why the child progresses to a higher level of organization. "Why give up one strategy for another?" they ask (p. 797). Their answer is negative feedback, as rotation of the lever 180° is the only action that works in their problem. For the spoon problem, the ulnar grip with the preferred hand gives partial positive feedback in the sense that food is obtained, but there are drawbacks. If the child continues transporting the spoon with the preferred hand, the awkward final position of hand and wrist is uncomfortable. The other solutions children arrive at (transferring the spoon to the other hand, repositioning the spoon on the table) take more time and energy to execute. Although all of these solutions work, the child eventually rejects the ulnar grip and settles on the most efficient solution of simply using the nonpreferred hand when they see that the handle is oriented in that direction. Why does the child progress on to find the most efficient solution? In the case of Koslowski & Bruner's (1972) lever problem, only rotating the lever sufficiently will bring the toy within reach. In the case of the spoon orientation problem, all solutions work in the sense of obtaining food, but only one is the most efficient, i.e., picking up the spoon with a radial grip in the first place. That all children ultimately arrive at this solution tells us that infants of 18–24 months are sensitive to the efficiency of their motor actions and, perhaps more important, that efficiency itself can be a goal. Inefficient actions, not simply a failure to reach the goal, provide sufficient negative feedback to drive the child to seek another solution.

The cross-sectional data of children's problem solving of the spoon problem led to several conclusions. Between 9 and 19 months of age, children come to recognize that a spoon is a tool for obtaining food and gradually learn how to pick it up properly. Through our manipulation of the handle's orientation, we found that children learn to perceive this as a constraining factor in selecting which hand should grasp the spoon. By 19 months, the majority of children picked up the spoon with an efficient radial grip, but this solution did not extend to other tools or even the spoon if its action was other-directed (McCarty et al. 2001b). Cross-sectional data cannot answer questions concerning the process by which children achieve this knowledge. Does the insight to use the nonpreferred hand when the handle points in its direction come suddenly, or is this an insight that builds over several weeks of spoon experience? How does having a preferred hand affect children's learning to solve the spoon problem? If children were given extensive experience with other tools, would the radial grip appear for the other tools as well as for the spoon? Does the difference between self-directed action and other-directed action persist over time within individual children, or is it a more fleeting difference, observed only around the time of first achieving consistent radial grips for the spoon? These questions are best answered with longitudinal data that span the period when children are gaining insight into how to pick up the spoon most efficiently. We have collected such data on eight children (R. Keen & J. Spies, manuscript in preparation), testing them weekly with both the spoon and the tools used by McCarty et al. (2001b).

When children are tested on the spoon problem only once, our data can tell us how many children at a certain age displayed a radial grip over trials. When children alternate their hands in concert with variations in the handle's orientation, we know they have assessed the problem perceptually and planned in advance how to execute a reasonable and efficient solution to grasping the spoon. The infants tested longitudinally between 10 and 17 months of age showed a gradual acquisition of radial grips (R. Keen & J. Spies, manuscript in preparation). The majority expressed incremental understanding of how to achieve a radial grip, with many reversals in the process. **Figure 6** plots the proportion of correct radial grips over all testing sessions for two children. Subject 4 in **Figure 6** is typical of most infants' progress, with high and low performance alternating, reaching stability after many weeks. Only one child of the eight appeared to have an "Aha!" session and acted on this insight thereafter (see panel for Subject 6 in **Figure 6**).

Consistent use of a radial grip on the other tools never appeared. Even at the very end of testing, children used ulnar and radial grips equally often for all of the other tools, whereas the spoon was consistently grasped with a radial grip (Spies & Keen 2010). This is a strong replication of the difference in planning for self- versus other-directed action reported in cross-sectional data (Claxton et al. 2009, McCarty et al. 2001b) and indicates the deep-seated nature of this difference. We do not know how long this tendency persists or its influence on other manual behaviors.

Does having a preferred or dominant hand help or hurt the child in solving the spoon problem? There are hints of how this works in the cross-sectional data in the age range when children are struggling to find a solution, around 14 to16 months. One of the most striking observations from this age range is to see a child extend the dominant hand but withdraw it before actually picking up the spoon in an ulnar grip. As the dominant hand is retracted, the nondominant hand is extended, ending with a proper radial grip. This scenario was observed in many children and informs us that inhibition of the dominant hand is part of the child's problem in achieving consistent radial grips. This led us to wonder how often the nondominant hand was used before children had solved the problem. That is, do children use a dominant hand almost exclusively until they hit on the solution of alternating hands with the handle's alternation? Or do they use both hands to some extent throughout the sessions in a random manner, while favoring the dominant hand? This question is critical because if children rarely employed the nondominant hand, this would imply a motor difficulty to be overcome. The reach and grasp would be clumsy and inexperienced if this hand were rarely used. If both hands were used routinely, however, the issue of how to pick up the spoon can be viewed more as a cognitive problem of figuring out that reaches for the spoon must alternate between the hands, dictated by the spoon's orientation.

Plotting hand use over sessions for each child, we found that all children typically used both hands, except for the rare session when one hand was used exclusively (Spies & Keen 2010). Interestingly, the dominant hand switched between left and right for four of the eight children across sessions, confirming that handedness is not stable during infancy, as others have reported (Corbetta & Thelen 2002, Corbetta et al. 2006, Michel 1983). The fact that children do show hand dominance during a session, even though it may be unstable, implies this plays a role in achieving radial grips. The learning process consists of first noticing their grip errors, then connecting these errors with the handle's orientation, and arriving at the solution of using the hand on the handle side. Because the nondominant hand has been used to pick up the spoon many times in past sessions, the motor act of using this hand is not a problem. However, the tendency to reach with the dominant hand must be suppressed.

Having a dominant hand may help children solve the spoon problem. Consider this: if there were no dominant hand, children's errors in grip would occur randomly and equally often between the two hands. Ulnar grips would occur for both hands for both positions of the spoon in an irregular manner. With a dominant hand making the majority of reaches, the child is more likely to notice the consistency of radial grips when the handle is toward the dominant hand and ulnar grips when it is turned away. If this analysis is correct, one would predict that blocking trials for each orientation would help the child to make the connection, and indeed this is what we found. In contrast to alternating the spoon's orientation as in McCarty et al. (1999, 2001b), we presented six trials in the handle-right orientation, followed by six trials in the handle-left orientation, counterbalanced for order of direction across participants (McCarty & Keen 2005). Two age groups were tested, 9 and 12 months, because infants in this range had never solved the problem in previous studies. The younger age group did not benefit from blocking trials for handle orientation compared to alternating orientations. In contrast, the 12-month-olds' radial grips rose to 77% on blocked trials, significantly higher than a group receiving alternating orientations (62%). It seems that when infants experienced an ulnar grip repeatedly if they picked up the spoon with the dominant hand, this led them to switch to the nondominant hand. In the longitudinal study, infants who showed a strong dominant hand during sessions were quicker to realize they needed to use the nondominant hand for certain orientations of the spoon.

TRANSFER OF STRATEGY USE IN PROBLEM SOLVING: RETRIEVING OBJECTS FROM TUBES AND WITH RAKES

It was not surprising that babies figured out how to get a radial grip on the spoon before they realized this solution for the other tools. The spoon is the first tool in our culture that infants use extensively on a daily basis. Several researchers have studied in detail how infants learn to use a spoon to self-feed (see Connolly & Dalgleish 1989 for an excellent study). These studies looked at how babies got food onto the spoon and the grip they habitually used, in contrast to our longitudinal study that varied handle orientation as a problem-solving manipulation. Probably the spoon is mastered before other tools because it employs the familiar hand-to-mouth action that babies begin exercising soon after birth. What was surprising in the longitudinal study was toddlers' failure to transfer the radial grip solution to other tools. Transfer has been found in other tool tasks. Brown (1990) and Chen & Siegler (2000) found that children transferred knowledge about the rake problem when both tools and target objects were changed. Because transfer of knowledge to new situations is so basic to efficient learning, we turned to the rake task (Brown 1990, Smitsman & Cox 2008, van Leeuwen et al. 1994) and the rod and tube task (Want & Harris 2001) to further study transfer.

The transfer of solutions or skills requires an abstraction of task components from one situation with application to a new situation. In the first study (Baker & Keen 2007), we presented children, 30 to 32 months of age, with the rod and tube task. The basic task consisted of the experimenter pushing a toy into the middle of a clear tube, then placing it in a mount in front of the child. Next, three rods differing only in length were arranged just beyond the tube, and the child was asked to select one in order to retrieve the toy. Only the longest rod was able to push the toy out of the tube; the others were shorter and could push the toy a little way but not far enough to retrieve it. This problem is fairly easy for this age child, and most solved it readily. They selected the longest rod first on about 70% of trials and used it to extract the toy, which we allowed them to keep.

After six trials of simple straight rods, a more difficult length problem was presented to test for transfer. The three rods were all the same overall length, but now crosspieces prevented full insertion into the tube. Again only one rod had the crosspiece placed close enough to one end so that the rod could be inserted far enough to expel the toy. Crosspieces on the other rods were placed toward their middle, resulting in partial insertion. If children transferred the concept of length as the characteristic that determined the effectiveness of a tool, they should realize that the length beyond the crosspiece was the portion of the rod that mattered, rather than overall length. Even after much trial and error, and repeatedly observing that the crosspiece prevented the rod from going into the tube, children failed at this task, with success on 45% of trials.

In follow-up studies, we determined it was not the visual distraction of the crosspiece that confused children, but rather the necessity to see variation in the overall length of the rods (R.K. Baker & R. Keen, manuscript in preparation). In other words, children 2.5 years of age did not evaluate the rod's length except in relation to its overall length. It is as if the children could not coordinate their knowledge about the rod and tube into a coherent whole. They knew that a rod could be used to dislodge the toy from inside the tube. They also knew that length of the rod determined success. Through trial and error they learned that only the portion of the rod beyond the crosspiece would go into the tube, but they did not combine these pieces of knowledge to guide a correct choice among the three rods with crosspieces. At first this result appears to conflict with Chen & Siegler (2000), who found that children of this age could select an appropriate rake among several that differed in length, and they transferred this knowledge to new rakes when superficial aspects of physical appearances were changed. However, in Baker & Keen (2007), the transfer problem went a step further in that length had to be calculated in a new way—from the crosspiece to the end of the rod. Children could no longer choose the long one and be correct. We found that if crosspieces were always placed at the end of the rods, and total length could be compared, children's performance recovered to the level of simple straight rods (R.K. Baker & R. Keen, manuscript in preparation).

Another more striking example of a failure to combine knowledge across problems comes from a study that combined the rake task with the rod and tube task (Metevier 2006, Metevier et al. 2007). By 2.5 years of age, children are able to use a rake to retrieve an out-of-reach toy, and after a brief demonstration or hint, they can select which of six tools will work (Chen & Siegler 2000). Likewise, they can readily solve the rod and tube task (Baker & Keen 2007). Our question was whether children could combine the solutions for two tasks that involve quite distinct actions to achieve a goal. The rake task requires a pulling action of one object on another, and the rod and tube task requires that one object be pushed into another.

We presented 36-month-olds with both the rake and the rod and tube task (counterbalanced for order across children), followed by a task that required sequencing both actions (Metevier et al. 2007). The rake and the tube tasks were presented in their most simple form, not requiring tool selection among alternatives, with just a single effective tool provided. For the rake task, children were presented with a ball out of reach and given a rake that could retrieve it. For the tube task, a toy was pushed into the center of a clear tube and a single rod was provided that fit the tube. All children received four trials on each task. The coordination task followed immediately: The tube with toy inside was mounted as before, the rod was placed beyond reach, and the rake was placed within reach. The question was whether children would use the rake to retrieve the rod, then use the rod to expel the toy from the tube. Eight trials were given, with the experimenter providing hints (e.g., tapping the head of the rake and saying "This might help" if the child failed to solve the problem after one minute) and eventually giving a full demonstration of the entire action sequence if the child remained unable to succeed.

Although children had previously performed both actions immediately prior to the coordination task, most found it extremely difficult to figure out what to do. Only four out of 16 children succeeded in sequencing their actions to obtain the toy with no help from the experimenter. An additional six children succeeded after verbal hints, five needed the full demonstration, and one never succeeded. Sequencing two different actions, each of which has a different goal, requires the child to bring together solutions from two problems. It seems that if a child can solve problem A and problem B independently, he/she should be able to sequence the solutions to succeed in problem A + B. But this was not the case.

In Metevier et al. (2007, Metevier 2006), the verbal hints to the children helped a good portion of them to coordinate the action of rake and rod to solve the problem. The hints consisted of verbal suggestions and gestures, the strongest of which was "You can use this (the experimenter taps the head of the rake) to get this (tapping the rod) and then get the toy." It is not clear how the children used this hint to guide their action, but one possibility is they visualized themselves making the sequence of actions. If so, they could subsequently carry out these actions in the order indicated and achieve success.

Gravity bias: the tendency of young children and animals to assume that falling objects move straight down on a vertical path

SCAFFOLDING PROBLEM SOLVING IN YOUNG CHILDREN

In a recent study, we attempted to provide children with a direct suggestion to use visualization to solve a problem (Joh et al. 2010). Children of 36 months, the same age as in Metevier et al. (2007), were presented with the problem devised by Bruce Hood (1995) in which three tubes, mounted vertically, are crisscrossed so that a ball dropped down a tube does not fall straight down. The child's task is to predict where the ball will emerge from the end of the tube by searching in one of three cups placed at the ends of the tubes. In the original study (Hood 1995), 3-year-olds were unable to predict where the ball would be and typically searched in the cup directly below the opening of the tube where they saw the ball disappear. Hood termed this the gravity bias, interpreting the children's behavior to mean they thought the ball should drop straight down from where they saw it disappear. Even after Hood attempted to train 3-year-olds on how to solve the tube problem, the gravity error persisted (Hood 1995).

In Joh et al. (2010), we took a group of 3-year-olds and instructed them to imagine the ball dropping down the tube, first with a single tube, then on test trials with three tubes intertwined. In the test trials, the experimenter held the ball over the top of one tube and said, "Can you imagine the ball rolling down the tube?" A control group (termed the Wait control) heard the experimenter say, "The ball is going to roll down the bumpy tube," to ensure that the slight delay caused by the experimenter saying the "imagine" sentence did not produce a correct response. A no-instruction control group heard the experimenter simply say "Look!" while holding the ball over the mouth of the tube.

One critical difference between Hood's original procedure and ours was the child's response. Hood dropped the ball and then had children search among three cups at the ends of the tubes. We gave children a cup and had them place it under the tube where they thought the ball would emerge. This procedural change allowed children to change their minds without penalty, and the switch behavior revealed details about their decision-making. Children received 12 test trials, with each tube used four times. On each trial, the experimenter held the ball over a tube and dropped it only after children indicated they had made a final decision and were ready for the ball to be dropped. Children given the imagine instructions made correct predictions on 63% of trials, which was above chance and significantly greater than the Wait control group, who performed at chance (29%) and marginally better than the group who received no instructions (40%).

As expected, when errors were made in all groups, the gravity error accounted for about 90% of errors. More interesting was the switching behavior. The imagine group switched their cup between locations more often than the other two groups, and this appeared to facilitate making a final correct choice. When the imagine group made an incorrect choice initially, they later switched to the correct location on 44% of trials. The two control groups switched away from an incorrect to a correct choice on 16% and 18% of trials. These groups typically did not switch after making an incorrect choice, preferring to stay with the gravity error. We inferred from this behavior that during the critical moment before the ball dropped, the children hearing the imagine instructions were able to visualize the path the ball would take and overcome their tendency to choose the tube opening directly under the position where the ball was held. Simply hearing instructions that contained key words such as "ball," "tube," and "roll" did not lead to a spontaneous use of visualization in the Wait group. However, children need the support of explicit encouragement to employ this strategy.

Although it is well established that adults can use visualization effectively in many tasks (e.g., Kosslyn 1975, Wohldmann et al. 2007), it is less clear whether this strategy is available to preschoolers. The evidence is mixed. Rieser et al. (1994) found that 3-year-olds could use visual imagery to imagine spatial locations of objects in another room, and Richards & Sanderson (1999) were successful in engaging 3-year-olds to use imagery in deductive reasoning. In Joh et al. (2010), we presented 3-year-olds with a problem-solving situation that could be facilitated by visual imagery, and they were able to follow the instructions. Their correction of errors points most clearly to the use of our instructions to imagine the path of the ball. However, direct instruction on how to solve the tubes problem was also found to aid preschoolers.

In another study that used Hood's apparatus to see if children could use verbal information to avoid the gravity error, Bascandziev & Harris (2010) had the experimenter give instructions on how the tube constrained the ball's movement. Specifically, children were told to follow the tube with their eyes to its end in order to determine where the ball would emerge. This adult testimony about the ball's movement enabled 3-year-olds (but not 2-year-olds) to solve the problem and search correctly. In neither Joh et al. nor Bascandziev & Harris were the children's eye movements recorded. It is possible that both the "imagine" instruction and the explicit strategy suggestion resulted in the same behavioral outcome for the children, i.e., they scanned the tube from top to bottom and arrived at the correct location. We are currently investigating this possibility in our lab. From these studies, it appears that preschoolers are able to use visual imagery or an adult's suggested strategy to solve problems. This incipient skill could be enhanced in educational settings to facilitate problem solving in a variety of situations, from mastering mathematics to improving personal relationships.

PROBLEM SOLVING: A CRITICAL COGNITIVE SKILL

One important critical aspect of planning behavior that develops with age is how far into the future one can act prospectively. Our very future as a species now depends on this. At a global level, we must take measures now to prevent the destruction of the environment we live in. Our governments, our citizenry, and we as individuals must look into the future and determine what steps to take right now to solve our global problems. The pressing issues of global warming, safe storage of radioactive waste from nuclear facilities, and the preservation of a clean water supply are just a sampling of the enormous problems we face as a species. Will we be like the people of Easter Island, who continued to cut down trees until their entire habitat was deforested? Will we be like the Anasazi in southwestern North America, who ignored climate change, continuing to practice deforestation and poor water management until the environment could no longer support their population? In these cases and others carefully documented in Jared Diamond's *Collapse* (2005), the populations engaged in practices that succeeded for a period of time, allowing the societies to overpopulate what the environment would support. By using short-term means, people were able to prosper for decades or even a few centuries, but such practices ultimately proved fatal, producing complete and often sudden collapse.

Diamond (2005) outlined four categories of mistakes in group decision-making that lead to a society's collapse: (*a*) the problem is not anticipated; (*b*) the problem is not perceived after it has happened; (*c*) the problem is perceived but nothing is done to remedy it; and (*d*) solutions are tried, but fail. We can see these same processes at work in children's problem solving. The 9-month-old picking up a spoon does so with the preferred hand and the handle goes into the mouth rather than the food end. Likewise, the 3-year-old searches directly below a hole when a ball is dropped, relying on knowledge that objects generally fall straight down—the gravity error. These examples show children failing to anticipate a problem and not perceiving there is problem until after it has happened. At slightly older ages children do perceive the problem but make ineffectual adjustments to remedy it. In the case of the gravity error, two studies have shown how children of 3 years (but not 2 years) will improve their performance if given mental tools like the suggestion to imagine the ball's path (Joh et al. 2010) or to follow the tube with their eyes to the bottom (Bascandziev & Harris 2010). With these verbal instructions from a knowledgeable adult, children are sometimes able to overcome their first impulse and arrive at the correct solution. The question is: Will modern societies be willing to listen to scientists who warn us of impending environmental crises? Will we encourage and give adequate resources to engineers and scientists to find solutions? How far have we progressed in our cultural development to solve problems whose consequences will be felt far into the future?

Finally, how can we teach our children to incorporate future-oriented thinking into their own decisions? We do not yet know how play and experience with materials enhance and facilitate later creativity and divergent thinking in problem solving, but there are good hints in the literature. Playful, exploratory learning leads to more creative and flexible use of materials than does explicit training from an adult (Smith & Dutton 1979). Preschoolers appear to inherently enjoy problem solving. They are sensitive to whether actions produce ambiguous or unambiguous results. Schulz & Bonawitz (2007) found that children played longer with a box when they were uncertain which of two levers caused a toy to pop up compared to a box whose lever function was unambiguous. In *A Mandate for Playful Learning in Preschool* (Hirsh-Pasek et al. 2009), the authors review the evidence that block play, model building, and playing board games such as Chutes and Ladders enhance children's mathematical abilities. It seems appropriate to end this review as I began it, with a plea for more research on how problem solving arises in development and how best to foster it through both home and school environments.

SUMMARY POINTS

1. Despite a decades-long history of interest in problem solving in children, there is a dearth of data on the origins of this critical cognitive skill. We need sustained, systematic research on how cognitive processes develop that lead to good solutions when problems are encountered.
2. Tool use offers many advantages to the study of problem solving because it shows planning and goal-directed behavior, occurring in sequential steps that can be easily measured. Both errors and successes are informative about the child's thinking and level of planning.
3. The study of tool use has taught us that children are driven by curiosity and a need to explore, characteristics emphasized by both Piaget and E. J. Gibson as basic to children's nature. It has also taught us that even very young children are sensitive to the efficiency of their actions, which leads to changing strategies in order to achieve more efficient motor behavior in pursuit of goals. The combination of a drive to explore and greater efficiency can have a profound influence on ultimate achievements as children practice a skill.
4. We know that very primitive problem solving begins early, before one year of age. By 8 to 9 months of age, infants will pull a cloth or a string to retrieve an object. More complex motor acts like grasping a spoon to self-feed take several weeks to become skillful, and this learning does not readily transfer to other tools.

5. Individual differences in some motor skills persist for at least one year. Research on children building a block tower revealed that superior achievement in some children at 18 months was still evident one year later. We do not know if these children were more skillful in general motor behavior or in this specific task.
6. Having relevant knowledge does not necessarily mean it will be used to solve a problem. Proper adult input can facilitate transfer of knowledge from one situation to another. The effective scaffolding of problem solving is a topic ripe for investigation.
7. A remaining challenge is to determine how we can best foster the development of problem solving in young children. We need to equip children with planning and problem-solving skills so they are ready to meet the evermore difficult and complex problems they will encounter.

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Figure 1

An 18-month-old child building a block tower in the study by Y. Chen et al. (2010). Note the sensors on both wrists for obtaining kinematic data.

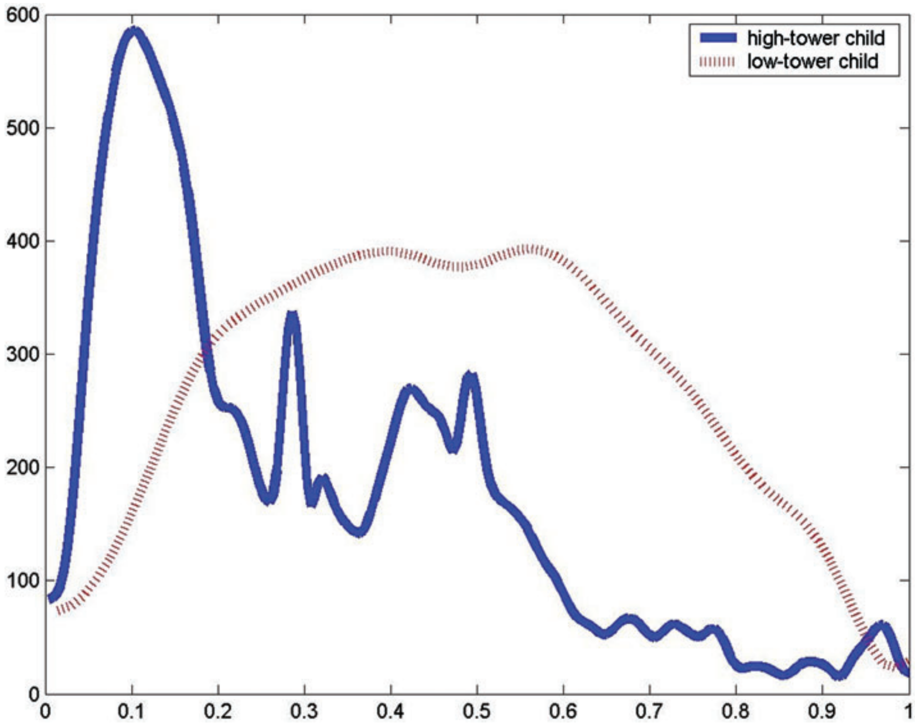

Figure 2

The velocity profile on a single trial for two children building a block tower. Note that the high-tower child's hand velocity peaks very early in the reach, allowing a lengthy slowing in preparation for releasing the block onto the stack. For this figure, reaches were normalized for movement time.

Figure 5

Photo of a child who picked up the spoon with an ulnar grip but nevertheless succeeded in getting food to the mouth. Children around 14–16 months of age typically persist in using their preferred hand, even though it results in an awkward twist at the end.

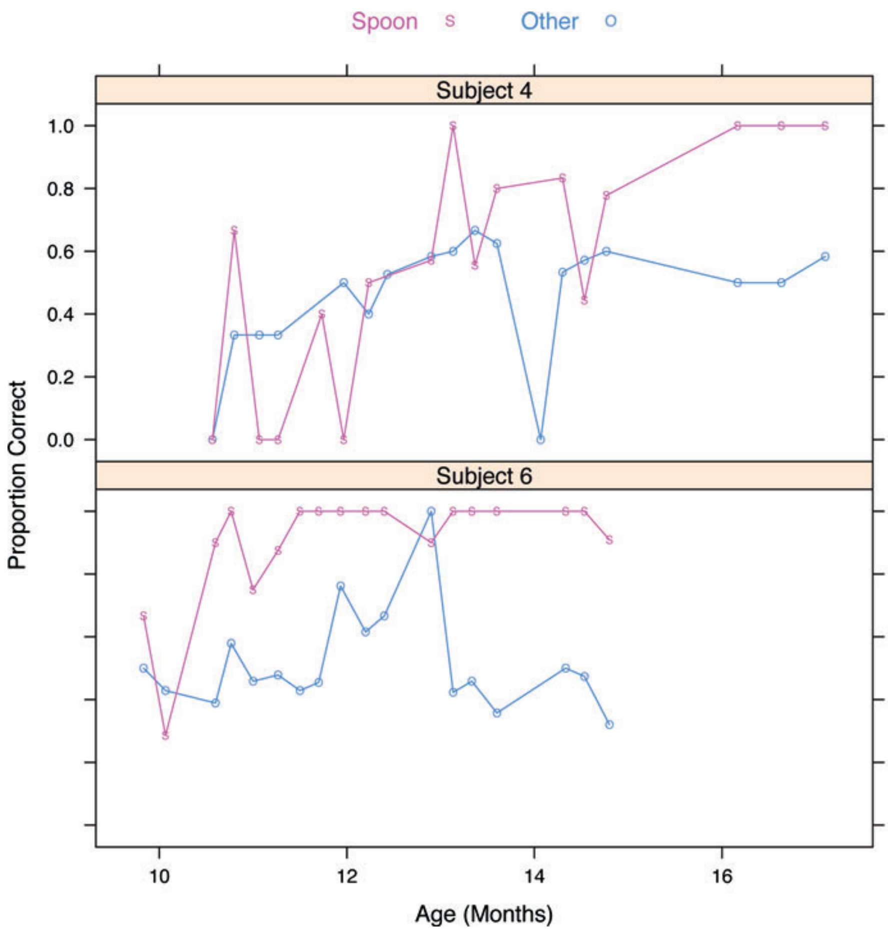

Figure 6

Longitudinal data from two infants showing acquisition of the correct radial grip on a spoon and other tools over several weeks of testing. The top panel shows a child who gradually learned to adopt a radial grip, with many reversals along the way. The bottom panel shows a child who learned quickly, achieved asymptote, and remained stable. Gradual acquisition was more typical for the group.

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