which the manipulation of teacher expectations was quite plausible because teachers had known pupils only for 2 weeks or less, 9 studies show positive effects (i.e., 90%, compared with Snow's 56%). Similarly, Snow reports the median effect size (*d*) for all 18 studies as .035, or .025 omitting the *Pygmalion* study. For the 10 studies of the more plausibly manipulated expectancies, the median effect size was .195, or .18 omitting the *Pygmalion* study. In an updated analysis of 19 studies of teacher expectancy effects,[5] Raudenbush estimates that the expected effect size (*d*) for studies having no prior teacher-pupil contact is .43, a substantial effect 3 to 6 times larger than the effects of aspirin described in my article[6] on which Snow is commenting.

Snow refers to the original *Pygmalion* study[7] as "discredited." But that should no longer be the issue. Even if Lenore Jacobson and I had never conducted our experiment, there are now too many new studies for even committed criticisms of disliked results to make the basic conclusion go away: Teachers' expectations can affect pupils' intellectual functioning. Science is the loser when new data have no effect on prior belief.

Notes

1. J.D. Elashoff and R.E. Snow, *Pygmalion Reconsidered* (Charles A. Jones, Worthington, OH, 1971).
2. The details of the statistical bias are given in R. Rosenthal and D.B. Rubin, *Pygmalion Reaffirmed*, published as Appendix C in Elashoff and Snow, note 1. Such biased data rejection has been recently discussed in R. Rosenthal, Science and ethics in conducting, analyzing, and reporting psychological research, *Psychological Science, 5*, 127–134 (1994).
3. Rosenthal and Rubin, note 2, p. 155.
4. L.V. Gordon and M.A. Durea, The effect of discouragement on the revised Stanford Binet Scale, *Journal of Genetic Psychology, 73*, 201–207 (1948); E.L. Sacks, Intelligence scores as a function of experimentally established social relationships between child and examiner, *Journal of Abnormal and Social Psychology, 47*, 354–358 (1952); other examples are summarized in R. Rosenthal, *Experimenter Effects in Behavioral Research* (Appleton-Century-Crofts, New York, 1966; enlarged edition, Irvington, New York, 1976).
5. S.W. Raudenbush, Random effects model, in *The Handbook of Research Synthesis*, H. Cooper and L.V. Hedges, Eds. (Russell Sage Foundation, New York, 1994).
6. R. Rosenthal, Interpersonal expectancy effects: A 30-year perspective, *Current Directions in Psychological Science, 3*, 176–179 (1994).
7. R. Rosenthal and L. Jacobson, *Pygmalion in the Classroom* (Holt, Rinehart and Winston, New York, 1968). Far from being discredited, that study was awarded First Prize of the Cattell Fund Award of Division 13 of the American Psychological Association; it has also withstood nicely the remarkably committed criticisms of Snow and his colleagues.

Infants Possess a System of Numerical Knowledge

Karen Wynn

A mathematical system can be characterized by a body of mathematical entities, along with a set of procedures for operating upon these entities to yield further information. For example, the system of euclidean geometry is composed of a set of geometrical entities (point, line, plane, angle, etc.), together with a system of inferential reasoning that can be applied over these entities to reveal further geometrical knowledge. Similarly, the natural numbers, in conjunction with arithmetical functions such as addition and multiplication, form another mathematical system.

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My colleagues and I have been investigating human infants' numerical abilities. The picture emerging from this research is one of impressive early competence and suggests that a system of numerical knowledge may be part of the inherent structure of the human mind: Infants can mentally represent different numbers and have procedures for manipulating these numerical representations to obtain further numerical information. In this review, I summarize these empirical findings, describe a specific model for how infants might represent and reason about number, and discuss briefly how this initial system of knowledge may relate to later numerical knowledge.

INFANTS CAN REPRESENT NUMBER

Infants can distinguish different small numbers of visual items, such as dots, points of light, and photographs of household objects. In studies showing this capacity, each infant is repeatedly presented with arrays containing a certain number of items, until the infant's looking time to the arrays decreases to a prespecified criterion (typically to half of his or her initial levels of looking).

Published by Cambridge University Press

At this point, the infant is considered to be *habituated* to the stimuli. Following habituation, the infant is presented with new displays, some containing the original number of items and some containing a new number of items. It is well known that infants tend to look longer at things that are new or unexpected to them; therefore, if infants can distinguish between the two numbers, they should look longer at the displays containing the new number of items. It has been found that when infants are habituated to displays of two items, they then look longer when shown three items, and vice versa, showing that they can distinguish the two kinds of arrays. Under some conditions, infants in this type of experiment will also distinguish three items from four.[1]

Infants can enumerate other kinds of entities in addition to visual items. After being habituated to arrays of two objects, infants looked longer at a black disk when it emitted two sequential drumbeats than when it emitted three; infants habituated to arrays of three objects looked longer at the disk when it emitted three drumbeats than when it emitted two.[2] Thus, the infants not only enumerated both the objects and the drumbeats, but also recognized numerical correspondences between them. This finding indicates that infants' numerical representations are abstract ones that can apply to input from different perceptual modalities.

We have recently shown that 6-month-olds can also enumerate physical actions in a sequence.[3] One group of infants was habituated to a puppet jumping two times, another to a puppet jumping three times. On each trial, the puppet jumped the required number of times, with a brief pause between jumps. Upon completing the jump sequence, the puppet stood motionless, and infants' looking time to the stationary puppet was measured. Following habituation, both groups of infants were presented with test trials in which the puppet sometimes jumped two times and sometimes jumped three times. Infants looked reliably longer at the puppet on trials containing the new number of jumps (Fig. 1a). The structure of jump sequences ruled out the possibility that infants were responding on the basis of the tempo or overall duration of the sequences rather than number.

In a second, similar experiment, we asked whether infants could discriminate between two- and three-jump sequences when the puppet remained in constant motion throughout each sequence; between jumps, the puppet's head wagged from side to side in an exaggerated fashion. In these sequences, the individual actions of the puppet could not be defined through a low-level perceptual analysis (on the basis of, e.g., the presence or absence of motion), but required an analysis of the pattern of motion in the sequence. There is, in fact, more than one way to pick out distinct actions in such a sequence; for example, one might pick out the individual jumps as distinct from the head-wagging activity and count them, or one might pick out the repeating pattern of "jumping followed by head wagging" and count its repetitions. Thus, the identification of discrete actions within a continuous sequence of motion is a cognitive imposition. Nonetheless, infants again looked significantly longer at the novel-number test sequences (Fig. 1b), indicating that they are able to parse a continuous sequence of motion into distinct segments on the basis of the structure of motion in the sequence, and to enumerate these segments. Thus, infants can enumerate complex, cognitively determined entities.

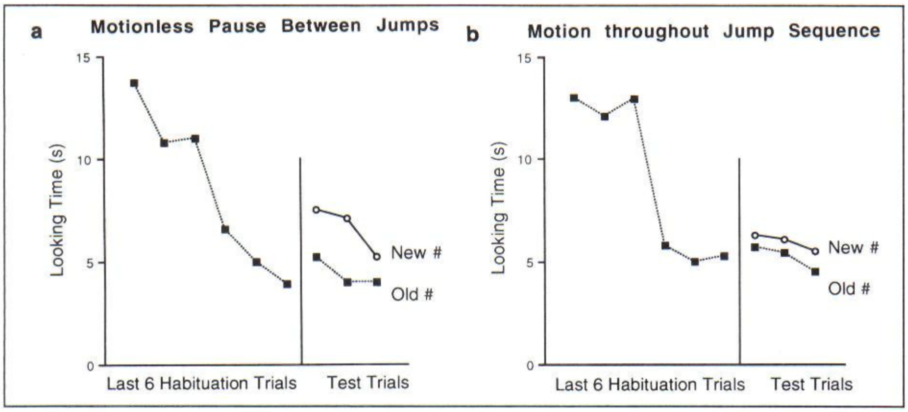

Fig. 1. Six-month-olds' looking times on the last six habituation trials and on old- and novel-number test trials for jump sequences (a) in which interjump intervals were motionless and (b) in which the puppet was in continuous motion.

Visual items, sounds, and physical actions are all very different kinds of entities. Typically, in experiments of the kind just described, visual items or patterns are presented to infants simultaneously, enduring together through time and occupying different locations in space; thus, the identification of visual items requires primarily an analysis of spatial information. Sounds, in contrast, have no spatial extent (though a sound may emanate from a specific physical location, it is perceived independently of it), but typically occur at different points in time and endure only temporarily, so their identification relies primarily on an analysis of temporal information. Finally, actions consist of internally structured patterns of motion that unfold over time, and so their identification entails an integration of both spatial and temporal information. The fact that infants can enumerate entities with quite distinct properties, presented in different perceptual modalities, indicates that infants possess abstract, generalizable representations of small numbers, and that these representations are independent of the perceptual properties of specific arrays.

INFANTS HAVE PROCEDURES THAT SUPPORT NUMERICAL REASONING

Possessing genuine numerical knowledge entails more than simply the ability to represent different numbers. A numerical system is composed not only of numbers, but also of procedures for manipulating these numbers to yield further numerical information. Infants might be able to determine numbers of entities without being able to reason about these numbers or to use them to make numerical kinds of inferences. If so, we would not want to credit infants with a system of numerical knowledge.

Studies conducted in my laboratory show that 5-month-old infants are able to engage in numerical reasoning: They have procedures for manipulating their numerical representations to obtain information of the relationships that hold between them. In these experiments, the infant is shown a small collection of objects, which then has an object added to or removed from it. The resulting collection of objects that is subsequently shown to the infant is either numerically consistent or inconsistent with the addition or subtraction. Because infants look longer at outcomes that violate their expectations, if they are anticipating the number of objects that should result, they will look longer at inconsistent outcomes than at consistent ones.

In the first experiment,[4] one group of 5-month-old infants was shown an addition situation in which one object was added to another identical object, and another group was shown a subtraction situation in which one object was removed from a collection of two objects. Infants in the *1 + 1* group saw one item placed into a display case. A screen then rotated up to hide the item, and the experimenter brought a second item into the display and placed it out of sight behind the screen (Fig. 2, top). The *2 − 1* group saw two items placed into the display. After the screen rotated up to hide them, the experimenter's hand reentered the display, went behind the screen, and removed one item from the display (Fig. 2, bottom). For both groups, the screen then dropped to reveal either one or two items. Infants' looking times to the displays were then recorded.

Pretest trials, in which infants were simply presented with displays of one and two items to look at, revealed no significant preference for one number over the other, and no significant difference in preference between the two groups. But there was a significant difference in the looking patterns of the two groups on the test trials: Infants in the 1 + 1 group looked longer at the result of one item than the result of two items; infants in the 2 − 1 situation looked longer at the result of two items than the result of one item (Fig. 3).

In another experiment, infants were shown an addition of one item to another, and the final number of objects revealed was either two or three. Again, infants looked significantly longer at the inconsistent outcome of three objects than at the consistent outcome of two objects (Fig. 4). (Pretest trials revealed no baseline preference to look at three items over two items.)

These results are robust; they have been obtained in other laboratories, using different stimuli and with variations in the procedure.[5] One study tested the possibility that infants were anticipating certain spatial locations to be filled and others empty, rather than anticipating the number of items in the display. One group of 5-month-old infants was presented with 1 + 1 situations, and another group was presented with 2 − 1 situations; for both groups, the outcome was sometimes one object and sometimes two objects. All the objects were placed on a large revolving plate in the center of the display, which was occluded when the screen was raised. The objects were therefore in continuous motion, so no object retained a distinct spatial location throughout the experimental operation. Nonetheless, infants looked reliably longer at the numerically incorrect outcomes, showing that they were computing over the number of objects, not over the filled-or-empty status of different spatial locations.[6]

A MECHANISM FOR DETERMINING AND REASONING ABOUT NUMBER

The ability to discriminate small numbers of entities precisely, and in some cases to perform numerical operations over these numbers, has been documented in a variety of warm-blooded vertebrate species as well as in human infants. This suggests that a common mechanism may have evolved to perform this function at a distant point in evolutionary history.[7]

The *accumulator* is a model of a mental mechanism for representing number, originally proposed to account for numerical abilities in rats.[8] The accumulator mechanism can account for both the ability to represent number and the ability to operate over these numerical representations.[1] This mechanism produces pulses at a constant rate; these pulses can be passed into an accumulator by the closing of a switch. For each entity that is to be counted, the switch closes for a fixed brief interval, passing the pulses into the accumulator during that interval. Thus, the accumulator fills up in equal in-

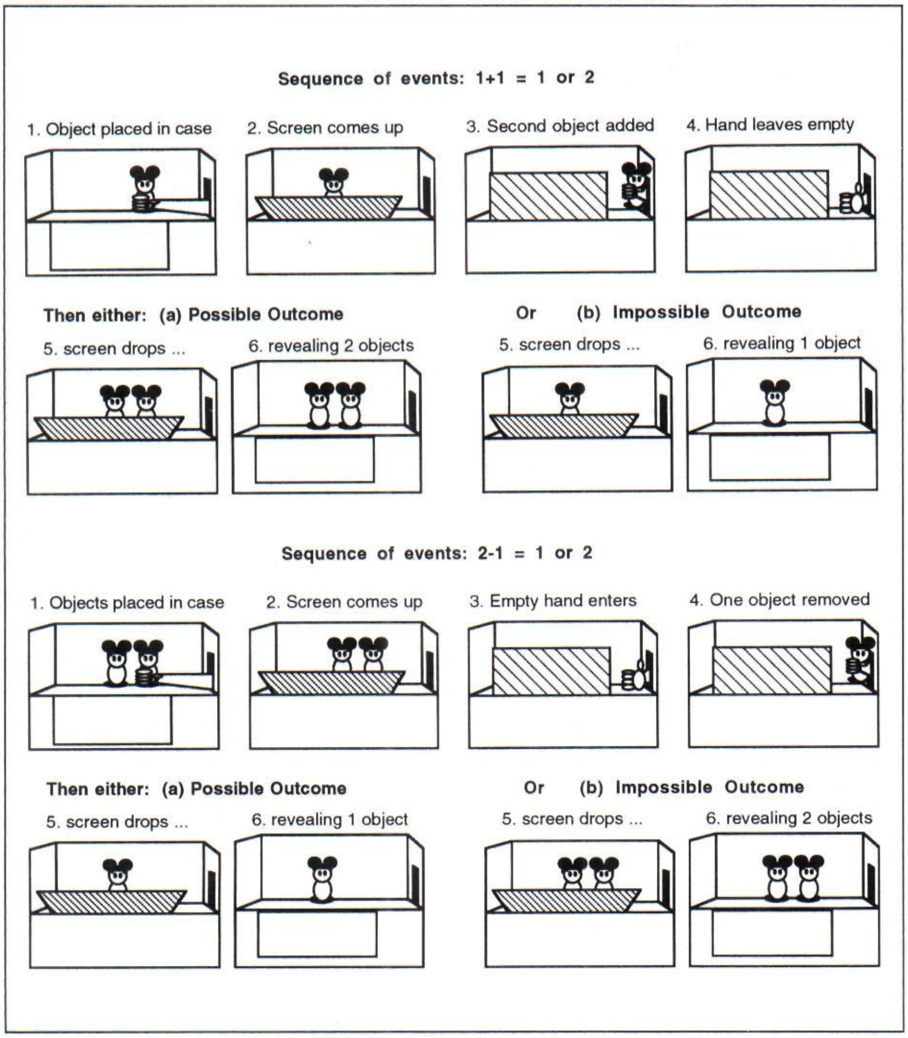

Fig. 2. Sequence of events shown in infants in Wynn,[4] Experiments 1 and 2 (courtesy of *Nature*).

crements, one increment for each entity counted (Fig. 5). The final fullness level of the accumulator represents the number of items counted. The entire mechanism contains several accumulators and switches to allow the counting of different sets of entities simultaneously.

As the accumulator is a physical mechanism and random variability is inherent to any physical process, the exact fullness level of the accumulator will vary somewhat across different counts of the same number of items. This variability will increase with higher counts; therefore, larger numbers will be less discriminable from their neighbors than smaller numbers. This feature of the model may account for why infants' ability to discriminate adjacent numbers is limited to smaller numbers, and why they less reliably distinguish 3 from 4 than they do 2 from 3.

Because the entire fullness of the accumulator represents the number of the items counted, the magnitudinal relationships between the numbers are specified in these representations. For example, 4 is 2 more than 2, or twice as large; the accumulator's representation for 4 has two more increments than the representation for 2, so the accumulator is twice as full. If the mechanism provides procedures for operating over these representations, infants (and animals) will be able to appreciate some of these numerical relationships. Addition, for example, could be achieved by "pouring" the contents from an accumulator representing one value into an accumulator representing another value. Subtracting one value from another could also be achieved: If Accumulator A represents a given number

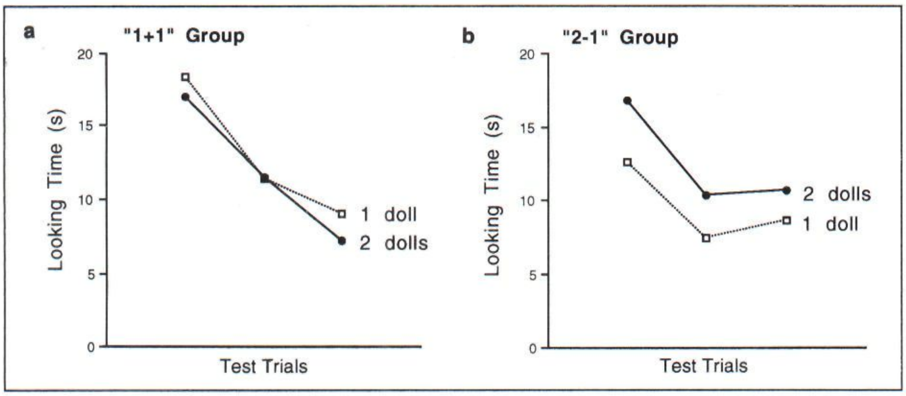

Fig. 3. Five-month-olds' looking times to outcomes of one doll and two dolls following event sequences in which one doll was added to a display of one doll (a) or one doll was taken away from a display of two dolls (b).

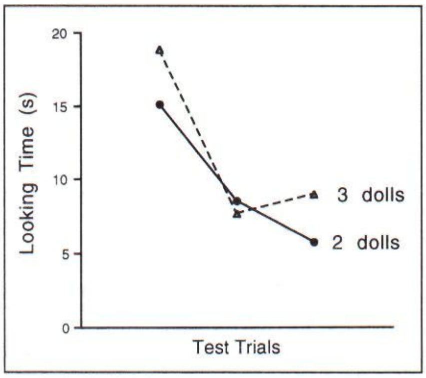

Fig. 4. Five-month-olds' looking times to two versus three dolls after viewing a sequence of events in which one doll was added to a display of one doll.

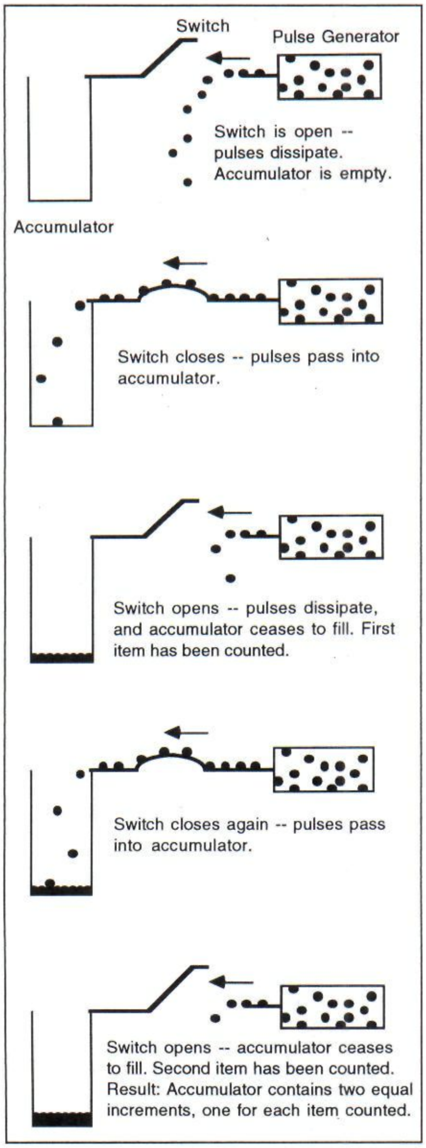

Fig. 5. Schematic diagram of the states of Meck and Church's[8] accumulator mechanism as it enumerates two items. The resulting fullness level of the accumulator is the mental representation for 2.

and Accumulator B represents the value to be subtracted from it, the difference could be obtained by pouring out, one increment at a time, the contents of A into an empty third accumulator, C, until A and B are equally filled. At this point, C will represent the numerical difference of the values originally represented by A and B.

RELATIONSHIP OF THIS INITIAL SYSTEM OF KNOWLEDGE TO LATER NUMERICAL KNOWLEDGE

Although an extensive body of numerical information is in principle accessible by virtue of the magnitudinal structure of the representations produced by the accumulator, access to these facts requires procedures for manipulating the representations in appropriate ways, and there will be practical limits on how the outputs of the mechanism can be manipulated. The kind of procedure required for determining the product of two values, for example, will be much more complex than that for determining the sum of two values; and that required for determining, say, the cube of a value will be more complex still. Infants' knowledge is therefore limited by the procedures they have available for operating over the numerical representations generated by the accumulator mechanism.

There are also limits to the kinds of numerical entities the accumulator mechanism represents. It does not represent numbers other than positive integers. Interestingly, an understanding of numbers other than positive integers emerges only gradually and with much effort, both ontogenetically and culturally.[9] For example, children have great difficulty learning to think of fractions as numerical entities; to do so requires expanding their construal of numbers as values that represent discrete quantities of individual entities. This kind of conceptual expansion has also occurred repeatedly in the historical development of mathematics. Zero, for example, was not initially considered a number, but rather was introduced simply as a place-holder symbol representing an absence of values in a given position in place-value numeral notation (so as to be able to distinguish, e.g., 307 from 37). Only eventually did zero come to be considered a numerical entity in its own right, by virtue of becoming embedded in the number system as rules for its numerical manipulation were developed. The emergences of negative numbers, irrational numbers, complex numbers, and so on have followed similarly gradual progressions.

These facts suggest that the positive integers—the very values that the accumulator model is capable of representing—are psychologically privileged numerical entities. Just as the development of mathematics as a formal system required a conceptualization of numbers that went beyond the positive integers, individual children must undergo a similar (though not necessarily so extensive!) reconceptualization. Gaining a better understanding of how children do this is crucial for ultimately understanding the role that infants' initial foundation of numerical competence plays in the development of later knowledge.

Acknowledgments— I thank Paul Bloom, Stanislas Dehaene, Randy Gallistel, and Tony Simon for stimulating and invaluable comments on a previous version of this article. Much of the work reported here was supported by an NICHD FIRST Award (Grant No. 1 R29 HD29857) to the author.

Notes

1. For a comprehensive review of these findings, see K. Wynn, Evidence against empiricist accounts of the origins of numerical knowledge, *Mind & Language, 7*, 315–332 (1992); K. Wynn, Origins of numerical knowledge, *Mathematical Cognition, 1*, 35–60 (1995).

2. P. Starkey, E.S. Spelke, and R. Gelman, Numerical abstraction by human infants, *Cognition, 36*, 97–128 (1990). When, as in this experiment, test stimuli and habituation stimuli are presented in different perceptual modalities, infants typically look longer at the matching stimuli in the new modality rather than the completely novel stimuli, possibly because the correspondence along a single dimension between two very different kinds of stimuli (e.g., pictures and sounds) is inherently interesting to infants.

3. K. Wynn, Infants' individuation and enumeration of actions, *Psychological Science* (in press).

4. K. Wynn, Addition and subtraction by human infants, *Nature, 358*, 749–750 (1992).

5. We have extended these results, exploring infants' numerical expectations in further situations; see Wynn (1995), note 1. For replications by other researchers, see, e.g., R. Baillargeon, Physical rea-

soning in young infants: Seeking explanations for impossible events, *British Journal of Developmental Psychology, 12,* 9–33 (1994); D.S. Moore, *Infant mathematical skills? A conceptual replication and consideration of interpretation,* manuscript submitted for publication (1995); T.J. Simon, S.J. Hespos, and P. Rochat, Do infants understand simple arithmetic: A replication of Wynn (1992), *Cognitive Development, 10,* 253–269 (1995).

6. E. Koechlin, S. Dehaene, and J. Mehler, *Numerical transformations in five month old human infants,* manuscript submitted for publication (1995).

7. For review and discussion, see chapter 10 of C.R. Gallistel, *The Organization of Learning* (MIT Press, Cambridge, MA, 1990).

8. For a detailed description of the accumulator model and of experimental support for it, see W.H. Meck and R.M. Church, A mode control model of counting and timing processes, *Journal of Experimental Psychology: Animal Behavior Processes, 9,* 320–334 (1983); see also C.R. Gallistel and R. Gelman, Preverbal and verbal counting and computation, *Cognition, 44,* 43–74 (1992).

9. See, e.g., R. Gelman, Epigenetic foundations of knowledge structures: Initial and transcendent constructions, in *The Epigenesis of Mind: Essays on Biology and Cognition,* S. Carey and R. Gelman, Eds. (Erlbaum, Hillsdale, NJ, 1991); M. Kline, *Mathematical Thought From Ancient to Modern Times,* Vol. 1 (Oxford University Press, Oxford, England, 1972).

Becoming Mindful of Food and Conversation

Michael Siegal

The ability to reason about mental states has considerable importance for cognitive development. Once individuals recognize that other people have knowledge, thoughts, and beliefs, they can use this *theory of mind* to their own and others' benefit in problem solving. As seen in a recent, huge surge of research, up until the age of 4 or 5 years, children often have difficulty with the tasks that have been devised to tap their understanding of mental states.[1] They frequently predict, for example, that persons with false beliefs about the location of an object will nevertheless search for the object in its true location.

One proposed explanation is that failures to take mental states into account when considering behavior are due to a conceptual deficit in development.[2] Another is that young children may not perform well on theory-of-mind tasks because their conversational inexperience leads them to misunderstand the scientific purpose and implications of an experimenter's questions.[3] The aim of this article is to show how children's performance can be facilitated by aligning their understanding of the task's purpose and relevance with that of the experimenter in the domain of food and safety, in which problem solving is related to survival.

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Philosophers of language, such as Grice,[4] have pointed out that adult conversation is characterized by rules or maxims that enjoin speakers to "Say no more or no less than is required. Try to say the truth and avoid falsehood. Be relevant and informative. Avoid ambiguity and obscurity." In communication between adults, it is usually mutually understood that the rules may be broken for certain purposes. For example, adults know that speakers may state the obvious for purposes of irony, or that they may speak more than is required out of politeness or curiosity. However, a communication barrier may prevent children who are inexperienced in conversation from identifying the purpose and implications of adults' questions. As a consequence, children frequently do not disclose the depth of their understanding when questioned in experiments. When given a false-belief task (e.g., "Jane wants to find her kitten. She thinks it is in the kitchen. It really is in the garage. Where will Jane look for her kitten?"), they may misconstrue the purpose of the question. Rather than recognizing that the purpose is to determine whether they understand where the character will erroneously look first, they may interpret the question as referring to where the character should look or will have to look to find an object. The pragmatics of adult questioning techniques can obscure children's authentic knowledge, and their incorrect answers may be misinterpreted to indicate conceptual limitations in their theory of mind.

THE EVOLUTIONARY SIGNIFICANCE OF A THEORY OF MIND IN THE FOOD DOMAIN

A key example concerns solving problems that are relevant to food and safety. According to an adaptive-evolutionary approach to intelligence, organisms striving for survival and reproductive fitness confront specific problems, such as finding food.[5] Solutions to these problems require an adaptive, spe-