THE PSYCHOBIOLOGY OF DOWN SYNDROME

edited by Lynn Nadel

A Bradford Book
The MIT Press
Cambridge, Massachusetts
London, England
1988

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QUALITATIVE DIFFERENCES IN THE WAY DOWN SYNDROME AND NORMAL CHILDREN SOLVE A NOVEL COUNTING PROBLEM

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Introduction

We believe that the roots of human cognition are best understood through the comparison of the performance of different populations of subjects on similar tasks and through the comparison of a given population's performance on a variety of conceptually related tasks. Here we show that comparisons of Down Syndrome and normal children's solutions for a novel counting problem shed light on the nature of counting knowledge.

There are two different accounts of the development of counting knowledge. One of these is based on the assumption that the capacity to form associations underlies all concept learning, no matter what the domain of the concept. The second account is based on the view that conceptual development benefits from an initial, albeit skeletal, set of domain-relevant principles or constraints. In the case of counting, the assumption is that a skeletal set of counting principles serves both to focus children's attention on counting- relevant inputs, and to support the build up in memory of a coherent representation of counting-relevant knowledge.

Cornwall (1974) concluded that Down Syndrome (hereafter DS) children learn to count by using associative, rote learning procedures. This suggestion gains support from some of our own data (Gelman, 1982) as well as the emerging consensus that DS individuals can learn by rote, despite their difficulties when required to use conceptual or rule governed learning strategies (e.g. Edgerton, 1979; Hartley, 1986). If so, the data from the DS children in this study should be best characterized by the first class of learning models. Additionally, if Siegler & Shipley (1987) and Fuson (1988) are correct in their contention that association models apply for the normal child as well, then the data from a normal control group should parallel those of the DS children. However, if our position, that normal preschoolers' knowledge of counting reveals the workings of counting principles (e.g. Gelman & Gallistel, 1978; Gelman & Greeno, in press), is correct, then the solution types of the two groups should be qualitatively different. What these differences might be will be considered in Section III.

Assume we find DS children's counting is better characterized by the association model of learning and that normal preschool children's counting is better characterized by the principle-first model. Obviously, we would not be justified in attributing the difference to the genetic mechanisms underlying the development DS. For the difference could well be mediated by a variety of other variables, and we would want to know how other categories of retarded children do. Despite this, we would be able to go beyond statements of "delayed" or "different" and say something quite specific about the ways in which at least DS children differ from normal children. Further, we would have some reason to conclude that normal children learn to count in a way that differs from at least DS children. The idea that normal children's learning about counting benefits from the availability of implicit principled knowledge of counting would gain weight. Finally, as we shall see, we can offer some suggestions about ways to alter arithmetic instruction for DS, and possibly other retarded, individuals.

Some Details About The Two Classes of Models

The Association-Reinforcement Model - The core of the learn-by-association account of how our young come to share our concepts comes from the British Empiricist theory of knowledge acquisition. The position is that we can explain concept learning if we grant humans but two pertinent capacities: (a) the ability to detect and respond to sense data and (b) the ability to learn according to the laws of association, these being the laws of contiguity and frequency. Associations are formed for the sensory inputs that occur in close (temporal or spatial) contiguity to responses and/or other sensory inputs: The strength of these associations is a function of the frequency with which the pairings are encountered. As these associations build up, it becomes possible to form associations between other inputs and those that are already established in memory. In this fashion one acquires more complicated associative representations of the world. Modern versions of the associative account of knowledge acquisition add further assumptions about the learner. Especially in developmental circles, the learner is granted the ability to imitate others and emphasis is placed on the role of reinforcement. Pairings between stimuli and imitations or other appropriate responses that are reinforced are more likely to be associated than those that are not. How does this kind of theory get applied to the case of counting?

Starting from a point of no knowledge or understanding about counting, acquisition proceeds as a function of opportunity to encounter, and be reinforced for using, examples of conventional counting lists and other response components of counting procedures. In a piece-meal way, children gradually build up a store of counting pertinent procedures, ones like listing the conventional counting string of words, repeating the last word said in a count list, pointing to objects, etc. The pace at which associations between procedures and the counting words are acquired depends on both a child's ability to form associations and a child's opportunity to be reinforced for the use of counting stimuli and responses. Eventually, when enough of these have been learned, the child is in a position to abstract the generalizations common to these. The result should be a principled understanding of counting (e.g. Baroody, 1984; Briars & Siegler, 1984; Fuson & Hall, 1983).

The Principle-First or Rational-Constructivist Model - As Feldman and Gelman (1986) note, the principle-first, or in their terms the rational-constructivist learning model, belongs to that class of models which grant learners some innate dispositions to focus selectively on those inputs that are relevant in a given domain. Whereas the association model presumes that it is sufficient to postulate the very general, all-purpose, mental ability to form associations, this class of models does not. The position is that it is necessary to grant that the young bring some implicit, yet organized, knowledge to the task of learning. The theoretical motivation for such an assumption derives from the fact that very young children do much to control the nature of their supporting environments. They are known to respond selectively to the stimuli presented to them. Further, there are times when the children actively seek out those inputs which foster their construction of knowledge within a domain (Brown, Bransford, Ferrara & Campione, 1983; Gelman & Brown, 1986). If young children are granted some skeletal representations, we have a beginning account of such self-initiated activities. The principles serve as enabling tools for learning. Skeletal sets of principles function to define the class of relevant inputs and therefore help the learner find those inputs that are relevant to learning in the domain in question. Similarly, they set the stage for the fleshing out, and development of, the skeletal principles themselves.

We prefer the second class of models, in part, because we see a need to account for how young children know what are relevant data for learning about counting and number concepts. Environments do not, by themselves, force themselves on the learners, who are actively involved in constructing their knowledge base. Instead learners select their environments; they determine what serves as relevant inputs. This concern for what we characterize as the problem of relevance is deeply related to Quine's (1960) discussion of "gavagai" and a review of it helps clarify the problem as it applies to number concepts.

Quine wondered how naive language learners come to know the intended referent of the sound sequence "gavagai", even if the speaker points in the direction of the target item, say a rabbit. For, in the absence of any clues to the contrary, the speaker could mean ear, furry stuff, space beside the thing, etc. How does the naive listener choose among these possible hypotheses, especially if the

listener is a beginning language learner? Why should the child presume the speaker means rabbit? Similarly, why should the child presume that the sounds "one", "two", are not labels for objects as a whole? Put differently, what is there within the learner as characterized by association theorists that would bias the learner to treat some speech data as label-relevant and other speech data as counting-tag relevant?

Unless we take the position that children must already share some implicit hypotheses with knowledgeable speakers, for example that a novel "word" uttered in the context of an object probably refers to the object as a whole, our young charges are guaranteed to end up with some unshared interpretations of the environment. In other words they will be at risk with respect to their ability to learn the concepts that adults have and want them to master. To help dispel the reader's doubt that naive learners would have such problems if we did not grant them some shared assumptions about the nature of counting, we turn to a consideration of the association account of how children might learn the English count list.

The learning-by-association account of counting is straight forward. The idea is that a knowledgeable speaker (e.g. a parent) points to each of a set of objects and then says "one, two, three," etc. The more the speaker in question does this, the more likely it is that the child will come to learn that the presented string of words can be used for counting. Let us assume that something like this has to be going on. Yet, it cannot be the complete story. For one, the point-and-label theory should also apply to the learning of color terms. Given the seemingly endless sets of colored preschool toys, picture books, and children's television programs that focus on color, it should be a trivial matter for young children to learn their color terms. But it is not: Surprisingly, the preschoolers have a very hard time learning color terms, this despite clear evidence that even infants perceive colors much as do adults (e.g. Bartlett, 1977; Bornstein, 1985).

Further, the point-label-associate account of how the children acquire the count words predicts that some of the children will think that the acoustic counterparts to the words "one" and "duck" are interchangeable labels for ducks. To see why, consider the book-reading ritual that occurs in this country with many a young child. Over and over again, one reads the same book. For sake of argument assume that the book in question has colored pictures of a duck and a pig on the first page. On one day the adult points to these depicted objects and says "duck", "pig" while doing so. On day 2, the same adult points to the same items in the same order and says "one", "two". On day 3, pointing occurs to the same items yet again, but now the adult says "yellow", "pink". Two clear predictions follow about the kind of learning that will take place if a child learns as outlined in the first model. A child could conclude that the duck should be labelled with all three of the words, "duck", "one", and "yellow". Alternatively, on the assumption that the different associations would interfere with each other, a child could think none of these terms apply. But neither of these possibilities fits with either what does happen, or what we want to happen to young learners.

Very young children keep separate the set of the count words from the set of object labels; they use them in their appropriate contexts (Gelman & Meck, 1986). Given this, we have argued (e.g. Gelman & Greeno, in press) there must be an alternative account of the way young children master counting. How it is that the principle-first account helps children sort out the count words and labelling words is taken up in Section III below. But for now, we note that the infants and preverbal toddlers respond in a numerical way to the displays that they could treat otherwise (Cooper, 1984; Sophian & Adams, 1987; Starkey, Spelke, & Gelman, 1983; Strauss & Curtis, 1981, 1984). Such data encourage us to think that our young help themselves determine what counts as numerically relevant input.

It is clear, infants have a great deal to learn about counting. Should anyone think we mean otherwise, they miss the fact that the principle-first model of learning is a model about learning. The next section expands on this theme.

How the Counting Principles Might Support Learning to Count

The Principles - To start to develop the principle-first account, we consider the one-one counting principle. This principle captures the fact that each and every item in a to-be-counted collection must be tagged once and only once with a unique tag. For the one-one principle to be put into practice, the counter must have available some set of distinct tags that is at least as large as the to-be-counted set. Counters must not skip or repeatedly tag individual items in the set. Put differently, the one-one counting principle yields the counting constraints, e.g. do not double count or skip items, that a plan must reflect for it to be an acceptable plan for counting. If one puts into action a plan that violates the constraints of the one-one principle, one will fail to honor the principle. Should this happen, we can say the counter followed an erroneous plan of action.

There is more to counting than what is captured by the one-one principle. Additionally, there are two further how-to-count principles, the stable-ordering and cardinal principles. These capture the facts that the set of tags must be repeatedly ordered, and that only the last tag used on a particular count can represent the cardinal value of the set.

Note that the counting principles say nothing about the kind of items one can count or the sequence in which items are to be tagged. As long as the how-to-count principles are applied, it matters not what items are collected together for a count. Nor does it matter whether items are counted in a row, one after the other, and so on. These latter two considerations led Gelman and Gallistel (1978) to add item-indifference and order-indifference princi- ples to the core of their proposed list of early counting principles. Their abstraction principle captures the fact that there are no constraints on the kinds of individual items that can make up a counting set. Similarly, their order-irrelevance principle serves to capture the lack of constraints on the item-tagging order.

Note also that the principles do not dictate the kind of tags one must use when counting. One does not have to use the conventional count words to count. In fact, one does not even have to use words when counting. Witness computers. The only constraints on the nature of the tags are those given by the one-one and stable ordering principles, i.e. that it be possible to treat them as all different and as an ordered set. Should finger positions, marks on the sand, short term memory bins, etc, be adaptable to his function, then fine. This consideration is what motivated Gelman and Gallistel (1978) to distinguish between numerons and numerlogs; they reserve the latter term for those tags which are count words in a given language.

Principles Help the Learner: Finding count lists in the environment - The above points regarding the absence of constraints on the type of items that can be counted, the source of the tags, and the order in which tagging can take place, bring us back to the question we raised in Section II. How do naive learners keep straight what string of words are or are not used for counting; how do children come to correctly sort their verbal environment into labels, words, color terms, etc., and do so without mixing them up at first? We submit they do this by taking advantage of the domain-specific principles they bring to the learning task. To expand this theme we contrast the counting principles with what is known about labelling principles.

Markman (1986) and Spelke (1988) each assume that children are biased to think that words used in the context of a novel object most likely refer to the object as a whole. Additionally, novices have a tendency to assume that once an object in a class has been assigned a label, that label applies to the other same-level members of the class (Au & Markman, 1987; Waxman, 1985). The idea is that like us, the young assume once a rose is a "rose"; a rose is a "rose" - despite differences in color, breed, size, number of petals, and so on, of the exemplars. Add to this our variant of Markman's mutual exclusivity principle, this being that each same-level class of natural objects or artifacts shares but one name, and we end up with the following proposal: Very young children's principles for labelling objects lead to their implicit hypotheses that: (1) Categories of objects share the same unique label; (2) once an item is labelled, it cannot be assigned another label if it is treated as a member of the same category; and (3) once assigned, that label must be assigned to other exemplars of the same-level category. If children make these implicit assumptions, they then have some clues as to what to expect over time as they continue to hear those words that serve labelling functions. For the words they have begun to assimilate to their lexicon should continue to follow the use rules that are dictated by the principles.

Now contrast the one-label-for-classes-of-like-objects constraints with the use rules that could operate given implicit knowledge of the counting principles: One way, although by no means the only way, to satisfy the stable order principle is to use a list of words to tag items. Therefore, on the assumption that this principle is available to structure the environment for children, ordered lists of words should be salient to them. But this principle cannot by itself tell the children how to use these lists. This depends on the availability of further principles. These principles indicate that, when counting, the same words can be used with different objects over trials, and, in contrast, that the same words cannot be used within a trial -- even if items are alike. Such constraints follow from the abstraction or item-indifference principle. In the absence of the stable-order and item-indifference principles then, the above list of the children's assumptions about labels could well lead them to think the count words are in fact labels for objects.

Thus, it is a combined consideration of the stable order and item-irrelevance principles that leads to the conclusion that number words are not names for objects but instead are tags for counting. Add to this Shipley and Shepperson's (1987) finding that young children will count any separably identifiable entities, including broken pieces of the same toy, and we see how they can know counting terms are not object classification terms -- at least not in the sense that labels or nouns are. The bottom line then, is that a child who is granted principles for organizing the verbal environment and its use over time, is given good reason to assume that labels and count words serve different linguistic roles and cognitive functions.

The counting principles enable a toddler to recognize when words are being used as count words and start to learn them as such. But it still remains a question as to how the child knows what to do with these words.

Principles Help the Learner: Finding counting relevant behaviors - When counting a set, one does not have to point to each item, start at the beginning of a row, arrange items in a row, count anything in particular, etc. There are multiple ways to keep track of the number of items used in a count-on strategy (Fuson, 1982). So are there multiple count strategies for solving a variety of arithmetic problems (Resnick, 1986). All of these count strategies are united by their common function: Solving the problem of determining the cardinality of a set. They do not serve to determine the cause of an object's acceleration, improve one's memory for places, learn the name of an object, or any of an infinite number of alternative goals.

How are we able to determine that these disparate events are in the equivalence class of possible procedures of counting? What gives us license to say of a variety of distinct behaviors that they are all instances of the class of counting behaviors? Again, our answer is that the availability of counting principles serves this function. For, if the constraints of these principles are reflected in procedure, then that procedure is an example of counting. Hence, the principles and their consequent constraints underlie our ability to define and identify members of the equivalence class of counting behaviors. Just as principles of counting help define the class of acceptable instances of counting.

Principles Help the Learner: Transferring or devising novel solutions to novel problems - The fact that principles make it possible to define the equivalence class of counting behaviors is related to another characteristic they possess. They serve as the basis from which the novel instances can be generated. This is because their constraints are ones that a planner must honor when generating a plan for counting (Greeno et al., 1984). Whatever else the requirements of a novel setting, the planner must honor the constraints of the principles if the setting calls for a counting solution. Otherwise, the solution cannot be considered an example of counting.

Should the planner have such a constraint list available, it can at least "monitor" the output of a solution with respect to whether or not it has met the constraint. Further, it can recognize inputs that signal failures to do so. Hence, there is the potential for generating an improved plan the next time round and doing so without explicit external feedback as to what to do in order to improve. We return to the issue of generality when we consider the kind of evidence one can use to attribute implicit knowledge of the counting principles to an individual.

A Caveat - To be sure, it is necessary to focus on that part of the input that is in fact relevant to the task of learning more about the domain. Still, it is not sufficient to do so. It is one thing to know what it is that one must master and quite another thing to do so. Knowing that the count words are the kinds of words one has to master in order to use symbols as tags does not guarantee that the learning will take place automatically. Indeed, in the case of the count words of English, everything we know about serial learning points to a protracted period of learning. So, although we can explain the fact that the young children and infants respond to the environment in numerical ways before they could have been given explicit instruction to do so (e.g. Cooper, 1984; Strauss & Curtis, 1984), this does not imply the patently false conclusion that the infants know all there is to know about counting. Nor does it mean that none of the learning that has to be accomplished will be done by rote. It simply means that children will get started on the right course, a course that is likely to be very protracted. For, given that they have to memorize, by rote, a long count list in English, and given that serial learning tasks are hard for college students, ultimate mastery of the count list itself should take a long time. For a discussion of the further complexity involved in acquiring understanding of the mathematical symbol system, see Gelman & Greeno (in press).

A Point of Contact - The idea that principles serve to direct attention to the relevant inputs that can foster knowledge acquisition in a given domain is consistent with various constructivist theories of mind. Cognitive scientists' contentions that prior knowledge in a domain determines what and how other materials are interpreted and learned (Bransford, 1979; Mandler, 1984; Schank & Abelson, 1977) represent a similar class argument. So does the Piagetian view that stimuli can serve as food for a particular cognitive activity only when there is a requisite structure with which to assimilate that stimulus. The Piagetian proposal that preschoolers cannot help but fail seriation tasks, this because they lack the requisite seriation structures, is but one illustration of the general position that mental structures are what support the interpretation and use of environments. From this perspective, when preschoolers invent counting algorithms to solve simple addition problems we give them, it follows that they must be using a knowledge structure that is characterizable in terms of counting principles.

Focus on Novelty

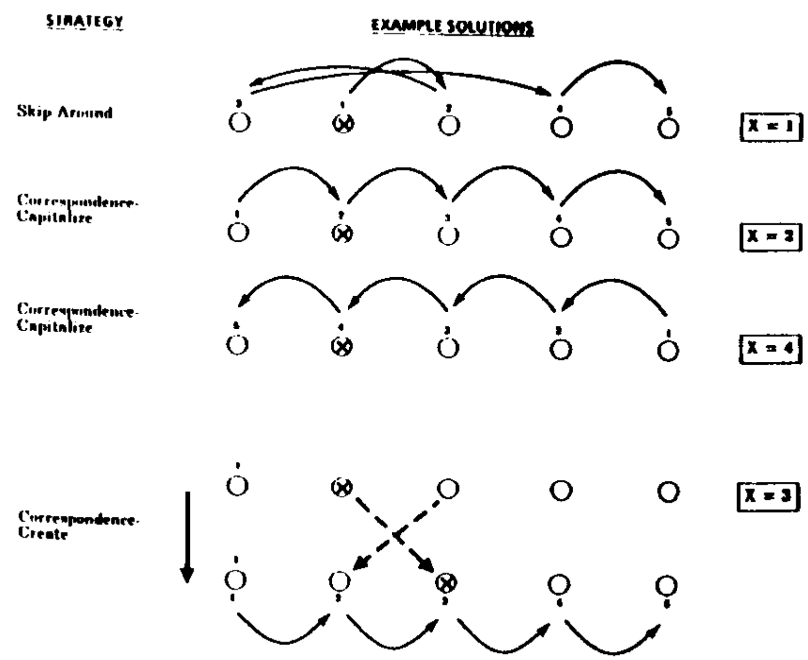
The above considerations of the way a principle-first model could help a child solve novel tasks led us to focus on how DS and preschool children negotiated a novel counting task. We wanted to know whether both groups of children would deal with the same task in different ways and, if so, whether the differences could be attributed to differences in the way counting was understood by the children in the two different groups.

The Constrained Counting or the "Doesn't Matter" Task - In order to assess young children's understanding of the abstraction principles, Gelman and Gallistel (1978) asked the preschool children to solve what amounts to a novel counting task which we will call the Constrained Counting Task. In the Gelman and Gallistel study, children started out simply counting a row of 5 heterogeneous items. The constrained counting task began when the children were asked to count the same display in a special (or different, or trick) way, this being to count all of the items by tagging the second item from the left "the one". That

trial complete, children were next asked to count again in the same special way, this time so that the designated target item was tagged "the two". Subsequent trials involved requests that the target item end up "the three", "the four" and "the five". There are a variety of solutions that one can use on this task. Some of the successful ones we have seen the children use are illustrated in Fig. 1.

Each row of Fig. 1 schematizes a heterogeneous set of 5 objects. The X inside a given circle indicates the position of the object to which the tagging constraint applied on that trial. The values in the right hand column give the numeral that was to be used for the targeted ob-

Figure 1. The schemata of possible solutions to the Constrained Counting Task. Take X = n to mean "make this, the target item, the 1, 2, ...or n". The numbers over the schematized items indicate the count word used; the arrows indicate the flow of points made by a child as she pointed to items.



ject. The actual observed pointing and tagging assignment orders are represented by the flow of arrows.

The solutions depicted in Fig. 1 are examples of ones generated by normal preschool children (Gelman et al. 1986). Row 1 shows that one way to succeed on the task is to start counting at one end, skip X if one has not yet gotten to the appropriate point in the count list, and then return to X when the tag in question is reached in the list. Hence, the label "Skip-Around" for this kind of solution. Another solution type involves recognizing that the target item is in the same relative linear spatial position from an end of the display as is the to-be-assigned tag in the count list. When this is the case, one can then count from the left or right. Hence, our choice of the label "Correspondence-Capitalize" for solutions shown in the second and third rows. (Note that such solutions cannot be used on all trials, including the kind shown in the first and last rows. Children who do not realize this, will "pass" some trials if they simply count as usual. For this reason, the reader should bear in mind that upcoming analyses of strategy use required that children used this solution selectively).

A final example of a possible correct solution, Correspondence-Create, is shown in the bottom row of Fig. 1. This solution involved moving items in the display to create a correspondence between the spatial position of the target item and list position of the to-be-assigned count word.

Down Syndrome Children Might Have Trouble with a Novel Task - Our account of how availability of counting principles might feed the generation of novel solutions involved several components. The first was that the principle-determined constraints serve to define the class of acceptable performances. So should a response be inappropriate, the child could recognize this was the case and at least start again. Second, if such constraints are operative, they can serve in the selection of possible responses in the first place. That is they can lead to the assembly of an appropriate plan. Third, if one is sensitive to the constraints on an acceptable plan, then one might well benefit from an experimenter's hints or reminders when one's solution failed to honor such constraints.

All of the preceding regarding the role of principles in the ability to solve a novel problem are variants on a common theme: That principle-governed searches for novel solutions can work to encourage children to monitor their own performance, to try out solutions, and to generate a plan that honors the counting constraints. Still, even if children have implicit knowledge of the counting principles, there is no guarantee that they will succeed on all novel problems. For, the children might know the counting principles but not have a sufficiently developed planning capacity -- no matter what the domain. In Greeno et al's (1984) terms, children might possess the relevant conceptual competence but be limited with respect to their procedural competence.

The Gelman and Greeno (in press) treatment of potential sources of error that contribute to variable performance highlights yet another reason why all of our subjects may fail. The generation of a competent plan of action is dependent on the planner's ability to monitor two sets of constraints: Those that pertain to the conceptual competence being assessed and those that are dictated by the task and the setting of the task. To deal with the latter a variety of interpretative competencies need to be well enough developed. These include ones that bear on understanding what to focus on in the instructions, the domain-relevant terms that are used in the instructions, as well as the rules of question-answering for the experimental setting (see also Donaldson, 1978; Siegal, Water, & Dinwiddy, in press; Gelman, et al. 1986). So limits on the ability to understand the instructions and rules of the setting could serve as a systematic error source, again even if children have implicit knowledge of the counting principles.

Fortunately, there are some clues in the literature as to how to proceed. Consider the following: Toddlers will systematically alter their search for missing objects (DeLoache, 1984); young children alter their approach to balancing blocks as a function of whether they generate a "theory" of balance or not (Karmiloff-Smith and Inhelder, 1974/75); as toddlers persist at playing with stacking cups they become better at applying an ordering schema (DeLoache, Sugarman, & Brown, 1985). Together these findings suggest that children who possess the requisite competence but nevertheless fail their first attempt on a novel problem, can come to succeed *if they are allowed to persist at the problem*. Without explicit feedback, performance improves over trials. Surely, self-generated trials could not lead to success unless some implicit knowledge of the principles in the domains in question were available to help children constrain, and therefore develop their successive efforts.

The foregoing considerations led us to a design that allowed children to repeat a trial, either on their own, or in response to hints from us. Children who are given hints or opportunities to start again cannot improve unless they have some way to interpret the hints or monitor the output of a new effort (Wilkinson, 1984).

Our design varied the way we built in the plan to repeat instructions, and give hints, depending on whether the subjects were from preschool or DS samples. The experimenters who worked with the preschool children were told that they could paraphrase instructions, or repeat crucial features of the instructions, or ask a child to do a trial again. The experimenters working with the DS children were allowed more options. In particular, they were allowed to introduce more explicit hints if the less specific ones failed to lead to improved performance. For this allowed us to see if the children that did not improve on their own could nevertheless recognize sample solutions and other explicit hints for what they were, that is relevant inputs to their problem at hand. They should if they have some implicit knowledge of the principles (See the Section - Principles Help the Learner: *Finding counting relevant behaviors*). But if the proposal that the DS children learn to count by rote is correct (Cornwall, 1974), such explicit hints should do little to improve performance (Campione, Brown, Ferrara, & Bryant, 1984).

Details of the Study

The Children: The Down Syndrome Children - The ten DS children who contributed the data presented here attended the Catholic day-school for retarded children. The Archdiocese of Philadelphia runs the school for free and although most of the children at the school come from Catholic families, applicants of all faiths are considered and accepted. The school is in a modern, well-equipped building, with a large, attractive setting in a quiet neighborhood in an upper middle class suburb of Philadelphia. It has a dedicated and talented staff, a fact that is validated by its receipt of major awards for teaching excellence.

The population served by the school is predominantly white and represents a lower-middle to middle-middle socioeconomic class. All children attending the school live at home with their families. They are bused to and from the school on a daily basis. The DS children in our study were so classified by the school staff who used a combination of diagnostic tools and medical records when first interviewing possible admittees. Details from these records were not available to us; still we had no reason to doubt the information we were given as to which of the children at the school were DS children.

The DS children who contributed the results presented below were all but one of the 11 DS children in a class of 21. (Equipment failures account for the need to drop the other DS child). The children in the class as a whole ranged in CA from 9 to 13 years (Median = 11 years); and MA from 3-6 to 6-8 (Median = 5.6). Their I.Q.'s (as measured in 19 cases with the Stanford-Binet, and two cases with the WISC) varied from 43-73. The range and medians for the DS children in the study were 10-13 CA years (Median = 10.6); 4-0 to 6-10 MA (Median = 5.8).

Some, or all, of our sample of children participated, along with other children at the school, in one or more of a wide range of studies conducted by a group at the University of Pennsylvania.[1] These included studies of language production and comprehension skills (such as the ones that Ann Fowler present in another chapter in this volume); causal reasoning; information processing styles; social cognition; and arithmetic skills. The data we present below come from the latter set of tasks. The focus is on the way children negotiated the Gelman & Gallistel constrained counting task and what the pretests revealed about their counting skills. On occasion we consider some additional data available to us, this because they inform the presentation.[2]

The Children: The Preschool Children - The preschool sample consisted of 16 4-year-olds (Range, 48-59 mos., Median = 53 mos.) and 16 5-year-olds (Range, 60-71 mos, Median = 63.5). About half of all of these children were recruited for participation in the study in our laboratory at the University of Pennsylvania. The rest attended a large, well-appointed and well-staffed Day Care Center in the Northeast of Philadelphia. The center is sponsored by the Philadelphia Federation of Jewish Agencies and favors children from homes with a single working mother or two working parents. Overall, the preschool sample served was predominantly white, and tended toward the middle-middle class.

We do not have MA levels for these children but given our information about a variety of pertinent socioeconomics factors, we think these would be slightly higher than their CA's. If so, all the 4-year olds and some of the 5-year-old children represent a sample that overlaps the DS sample with respect to MA. Some children have participated in studies other than the pretest assessment of their counting levels and the constrained counting task. But none of these involved arithmetic related stimuli.

The Children: Counting in the DS School Curriculum - We have worked in two schools that serve retarded children in the Greater Philadelphia Area. In both, counting instruction is a featured part of the school day. Children get daily practice reciting the count list, counting sets of objects, naming written numerals, and learning simple addition facts. In addition, they encounter counting experience at circle time, in the gym, on the playground, etc. In short, theirs is a learning environment that is inundated with counting-relevant inputs. Our preschool children were clearly exposed to a variety of counting opportunities, either at their preschool setting or in their homes; we have no reason to doubt that the Saxe, Guberman & Gearhardt (in press) observations of such inputs applies to the children in our study. Nothing in the study or our own observations of preschoolers in a variety of settings suggests that the exposure of normal preschoolers to explicit instruction in counting is as intense and pervasive as it is in the curricula at the DS children's school.

Procedures - The DS and preschool children reported on below are best thought of as participants in two different studies that have overlapping conditions. Both the studies included pretests of counting levels and a common constrained counting condition. The common constrained task in the experiment proper was the one that was introduced above: all the children were shown a heterogeneous, five-item linear display and asked to count this row. Next they were asked to make a target item "the one", while counting all items; then they were asked to make a target item "the two"; next they were asked to make the target item "the three"' then "the four"; and finally "the five". For half the preschool children the target item was always the second one from the left; for the other half of the preschool children, the target item varied. In the DS study, th. target item could occur in the second, third, or fourth position in a row.

In both studies, two experimenters worked with each child in a quiet setting out of the classroom. During the pretests for counting, one kept track of the children's responses, including whether they pointed as they were counted. During the experiment proper, one experimenter interviewed the child, and the other video-recorded the session. The experimenters in each study were told that they could repeat or paraphrase the instructions. The experimenters for the Preschool study were told they could not give their charges any explicit hints.

As indicated in Section IV, the experimenters who were working with the DS children had no prohibitions regarding explicit clues. As we will see, they often did offer very explicit help. This is perhaps not too surprising. For, the same experimental team found it necessary to add a demonstration phase to our counting pretests after we noticed that many of the children failed to coordinate their recitation of count words with their points. Since our goal during the pretest was to determine what the children could do in the way of counting, the fact that never before had we run a demonstration test phase with preschoolers did not seem reason enough to avoid doing so with the DS children. (For further details, see below).

In both the DS and Preschool studies, the children were given additional variations of the "doesn't matter" task, ones introduced to provide data on whether the children could be flexible in their choice of solutions. The DS children were given an 8-item version of the task after they completed the 5-item version. When the set size increases, there is a greater chance of forgetting which item is the targeted one. Therefore, one must either remember its position in the row or do something to make the item distinctive, e.g., move it up above the row a bit, rearrange the order of items in the row. Failure to do these and to instead persist at using developed solutions could index a lack of flexibility.

Preschool children were also tested with circular arrangements of a 5-item heterogeneous display. When items are in a row, what is the beginning and end are given by the arrangement itself. In the case of a circle, children have to monitor the items if they are to avoid violating the constraints of the one-one principle. They cannot simply do what they are used to doing, which is to keep counting until they reach the end of the row. There is no "end" unless one constructs one oneself. So again, children who use the same solutions for both kinds of displays could be characterized as inflexible.

Thus, in both studies we have data from a common condition as well as data from variations on this condition, variations that might shed light on the extent to which the children in each sample can be flexible and change plans given a change in the setting.

Assessments of Basic Counting Abilities - We were able to assess the children's counting levels in the two ways summarized in Table 1. The first relied on the regular counting trial that occurred just before the children had been introduced to the requirements of the constrained counting task. The pertinent summary statistics for this trial are shown in the top half of Table 1. The other measures of group levels of counting prowess are summarized in the bottom half of the table and were based on pretests designed for this purpose. Note that the children were tested more than once on a given set size so that we could determine whether they counted reliably.

Also note that the DS children were given a second counting test. Like the preschool children they were first tested without any demonstrations. Following that session they were tested in a Demonstration condition. Now the

Table 1
Down Syndrome And Preschool Samples Counting Skill

Data Source & Counting Principle(s)@	Source Of Data And Index Of Counting Skill: 4 YRS	5 YRS	DOWN (NO DEMO)	DOWN (DEMO)
Constrained Count Trial to Start Experimental Task				
1-1 and Stable Principles				
X-5	94	100	100	----
X-8	----	----	90	----
Pretests				
1-1 and Stable Principles				
X-5	86	100	60	90
X-8	81	88	70	80
Cardinal Principle				
X-5	86	94	40	90
X-8	38	69	20	70

@ DS children had 3 count trials per set size and had to get 2 of 3 correct to be credited with the one-one and stable principles; at least one correct to be credited with the cardinal principle. Preschool children only had 1 counting trial per set size, unless they erred in which case a further trial was administered. If correct by the time the trial ended, they were scored as having the one-one and stable principles. See the text for a description of the separate cardinal task they received.

experimenter first counted, and while doing so, made sure to point to and/or move each item as it was tagged.

As can be seen in the top half of Table 1, the two preschool and the DS groups of children counted equally well when tested with the row of five heterogeneous items that would serve as the stimulus set for the constrained counting tasks. This means that they all started the constrained counting tasks from a common performance level. Unfortunately, it is not clear that children in the different groups were in fact all equally good counters. Our reason for saying this is presented in the bottom half of Table 1.

If, for the moment, we ignore the DS children's Demonstration scores, we can see that both groups of preschoolers outperformed the DS children. It is only after the experimenter had herself counted the set and as she did, touched each item and counted aloud, that DS children could perform as well as either preschool group. Even still it is not clear that the DS children were as good as the preschool children at applying a principled understanding of cardinality. For the preschool children had a harder cardinal task. They had to produce sets of 5 and 8 items, and do so by drawing the target number from a bag. In contrast, the DS children simply had to answer the "How Many?" question that followed their counting of a set. Some researchers have contended that this question can be answered solely on the basis of a rotely learned tendency to repeat the last tag said when counting, and hence, not on the basis of a principled understanding of cardinality (e.g., Fuson, Pergament & Lyons, 1986). The preschool children could not pass our assessment of their use of the cardinal principle by simply repeating the last count word used on a given trial. They had to keep the target value in mind and then generate that value by drawing N items from a bag. In other words, they had to understand the role that counting played in the generation of the cardinal value. The DS children did not necessarily have to use the same level of understanding since they did not have to perform a task that required it.

In sum, the data on how well the DS and preschool children count suggest that they are comparable when it comes to meeting the requirement for participation in the novel task. However, there is a suggestion that the preschool children, especially the 5-year-olds, had a better understanding of the nature of counting. Composite pretest scores, ones that take into account the tendency of each child to be consistent, (that is, never err in applying the one-one and stable principles), and to be able to give some indication of the cardinal value of sets as large as 8, fit well with this suggestion. The DS children were tested three times on each set size. If we ask how many of them honored the one-one and stable order principle on at least two of these trials and for both set sizes 5 and 8, we find that only two of the ten DS children met these criteria and hence got classified as Excellent counters. One was 12 years old, the other one was 10 years old. Their respective MA's were 6.10 and 5.9, both of which exceed the Median MA for the DS group as a whole. In contrast, 37.5 and 62.5 percent of the 4-year-old, and 5-year-old children met the criteria set to classify them as Excellent counters.

Additional data on the DS children's numerical abilities suggested to us that the two excellent counters in this group might differ qualitatively from the remaining DS children in our sample. As a check on this possibility, we often will treat them as a subgroup (DS Group A) and therefore analyze their data separately from those for the rest of the group (Hereafter DS Group B). For the constrained counting task could well pick up differences in principal understanding as well as the ability to take advantage of these when problem solving. Before turning to the data from the experiment proper, some details regarding data reduction need be discussed.

Transcriptions of the videotapes - Transcriptions of videotapes from the constrained counting trials were built up around the format shown in Fig. 1. Such diagrams were placed alongside column entries described below. But for one case, every attempt at a solution, no matter whether it was correct or not, was displayed on the transcription sheets in a manner like that shown in Fig. 1. The only time this was not done was when a child started to count the first item, stopped, and started again. In this case, the self-generated restart of the trial was noted in a <u>Comments</u> column. Thus, for every initial test trial and every repeat of that trial, we ended up with transcripts that showed the children's sequence of points and count words. In addition, the separate columns to the right of these diagrams were used to enter transcripts of all comments and questions, as well as comments on the source of these (child or experimenter). These comments were entered so as to indicate when (before, during, after) the talk occured relative to the counting behaviors diagrammed for the trial. If the experimenter demonstrated anything, this too was described in detail. Further columns on the transcription sheets, and again for each diagrammed entry, were used by two transcribers who together coded whether and when the children hesitated, counted slow or fast, paused, or made eye contact with the experimenter.

An independent observer was trained to read our transcripts and then used 17 of these to see if she agreed with a computer printout of summaries that were generated from these. These summaries included rates of success per trial, the number of times a child encountered a trial, whether children hesitated, restarted a trial (with or without a probe), the amount of speech produced by the experimenter between repeats of a trial, etc. In all, excluding the diagrams and the details on these, the second observer checked our transcripts against 4060 separate sheet entries and agreed with them on all but twenty-nine occasions. Further, she only needed to return to three of the actual videotapes themselves to make sense of an entry on the transcript. This indicates that we succeeded at developing an interpretable transcription of the tapes and that summaries based on these were reliable. Hence, the coded data served as the source of input to the subsequent analyses.

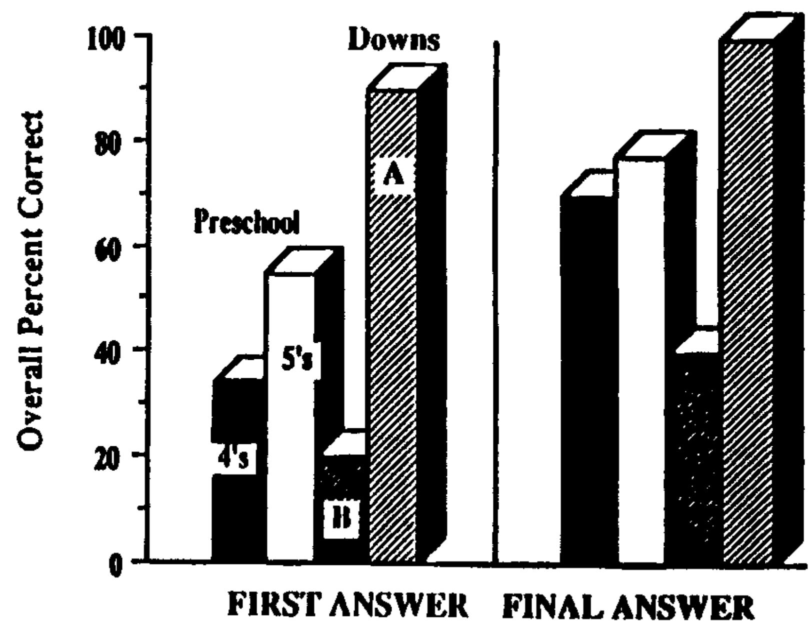
What the Study Reveals About the Nature of Counting Knowledge

Overall differences in the Ability to Deal with Novelty - Our first pass at finding answers to our questions involved a consideration of overall levels of success on the constrained counting task. Fig. 2 plots the overall tendencies of children to generate successful solutions

on their very first encounter with the question or by the time the trial had ended. (Recall our plan to allow the children to repeat a trial, either on their own or after receiving hints). Three salient results are shown here.

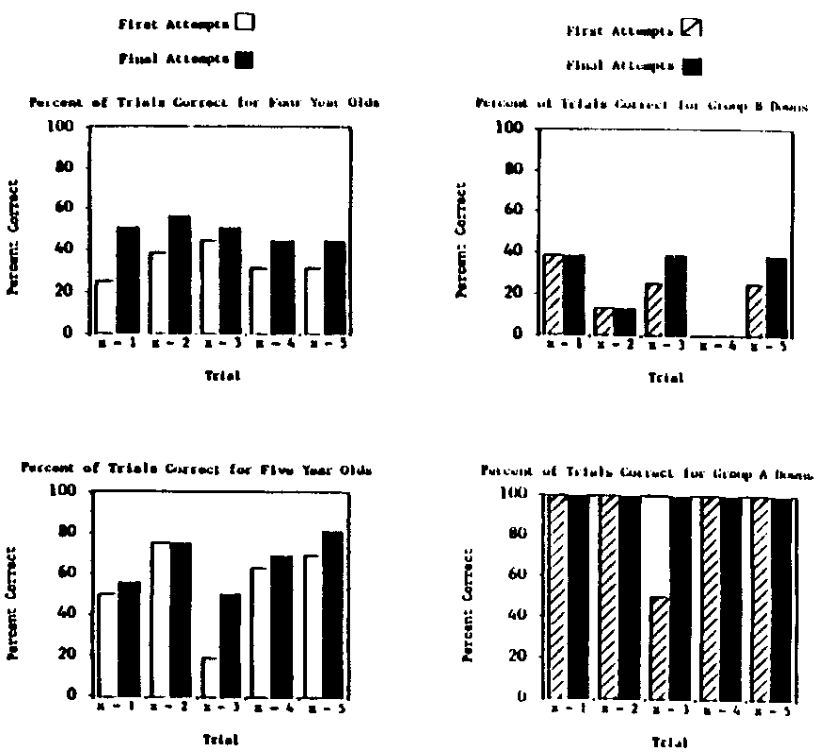
First, if we focus on the two DS groups of children (A and B), there is a clear difference favoring those DS children we identified as excellent counters (Group A). In fact, the two DS children performed at ceiling levels. Second, although both preschool groups outperform the remaining DS children, the two DS children in the A Group did best of all. Finally, the preschool children, especially the 4-year-old, improved much more than did the DS

Figure 2. The overall performance levels of success for each group of children tested on the Constrained Counting Task.



B group of children as they went from their first to final effort with the trial. This is our first clue that the bulk of the DS sample might not have benefitted from hints or self-corrected their initial efforts. A more de-

Figure 3. The Percent correct responses on the Constrained Counting Task shown as function of trial kind, group, and whether the response was the first one for a trial or not.



tailed consideration of these results begins to support the hypothesis that the B group of DS children represent a qualitatively different sample with respect to counting knowledge.

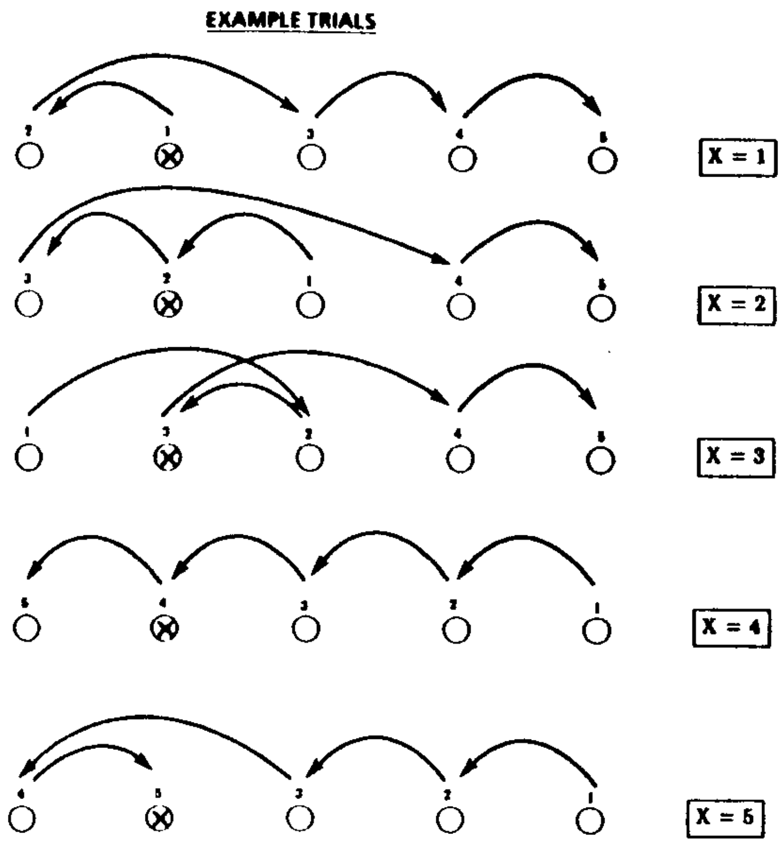
Differences in Across-Trial Profiles - Figure 3 presents a trial by trial summary of success levels, again as a function of whether success occurred on the first attempt with a trial or not. Recall that each of the trials varied in terms of which tag (1, 2, 3, 4, or 5) children were asked to assign to a target item. The data for the preschool children are shown on the left; those for the DS children are presented on the right. Again we see a persistent and positive effect of allowing preschool children to attempt a solution more than once. More importantly, a consideration of each bar graph suggests how children in each group differed.

The 4-year-old children generated what is becoming a familiar pattern for us. As in other studies, children of this age improve both as a function of the opportunity to retake a trial and as they moved from X = 1 to X = 3 (See Gelman et al, 1986 for another example). So although they did not do especially well when they first confronted the novel task (X = 1), they clearly "caught-on", despite the fact that they never were told explicitly what to do. The fall-off for X = 4 or 5 most likely reflects the working of fatigue and difficulty factors (cf. Gelman et al., 1986). Contrast these youngsters' performance with that of the majority of the DS children (Group B in the upper right hand corner). It is clear that there was no effect of repeating the trial for either X=1 experience to the X = 2. In fact, there seems to have been negative transfer from the X = 1 experience to the X = 2 trial. And although there appears to have been some learning effects by the X = 3 trial, these dissipated [See Wishart's chapter in this volume for a similar unsteady pattern of responding in DS infants and toddlers.]

The bottom panels in Fig. 3 show that both the 5-year-olds and Group A DS children benefitted from the opportunity to repeat trials and did so just where one might expect this to have happened -- on trials that presented some difficulty. In this regard the X = 3 trial results are especially salient. To understand what might have happened on the X = 3 trial, it helps to refer first to Fig. 4 which illustrates one possible set of solutions across all values of X, given that X is always in the second position.

From Fig. 4, one can see that the X = 3 trial places the greatest number of demands on the child. In the given example, it is the only trial which requires the child to skip an item more than once. A little reflection makes it clear that this is also the trial where a child would

Figure 4. Schematized solutions to a set of trials where the target item was always the same across trials with differing values of X.

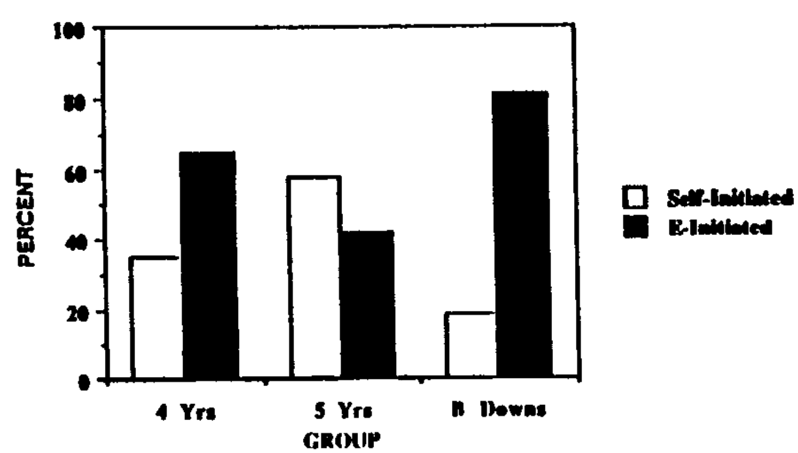


benefit most should she use a Create-Correspondence solution. Yet the Create-Correspondence solution is hardly one that the child is likely to have encountered before. So there should be a temporary fall off in performance. Such considerations help explain why the drop in performance on the X = 3 trial. (Although not all of our Ss were run in the exact condition shown in Fig. 4, many were.)

The data summarized in Fig. 3 add support to the hypothesis that even our youngest normal subjects generated solutions that benefitted from their implicit knowledge of the counting principles. For, just as the 5-year-olds benefitted from time on task, so did they. And just as the 5-year-olds then improved on subsequent trials, so did they. In fact, they turned to trying to generate correct solutions as soon as they got their instructions.

It begins to look like children's answers on the constrained counting task were determined by two qualitatively different paths. The preschoolers as well as two of the DS children responded as if they were using principled knowledge. The same does not seem to be the case for the remaining eight DS children in our study. To see whether this is a reasonable conclusion, we turn to yet more detailed considerations of the ways children negoti-

Figure 5. Source of a child's repeat of a given trial: the child or the experimenter.

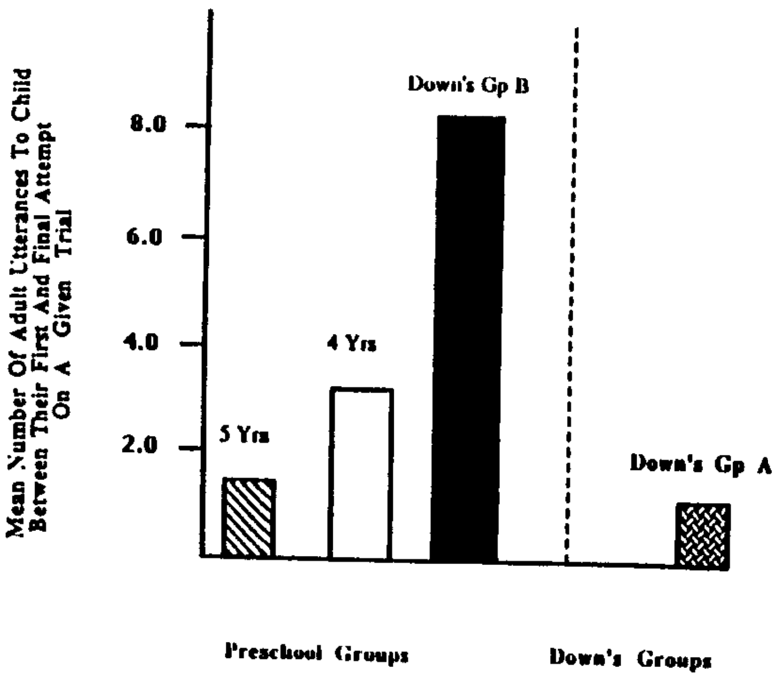


ated the constrained counting task as a given trial proceeded.

Differences in Follow-ups to an Initial Unsuccessful Attempt - We have argued that the children who have implicit counting principles as a problem-solving resource are also in a position to self-initiate a second attempt. The following presents 2 lines of evidence that indicate that the preschool children, but not the Group B DS children, did just this.

In Fig. 5 we plot the extent to which a child's tendency to repeat a trial was self-initiated as opposed to experimenter-initiated. Since the two Group A DS children made so few mistakes to start, they are not represented in this or related analyses.

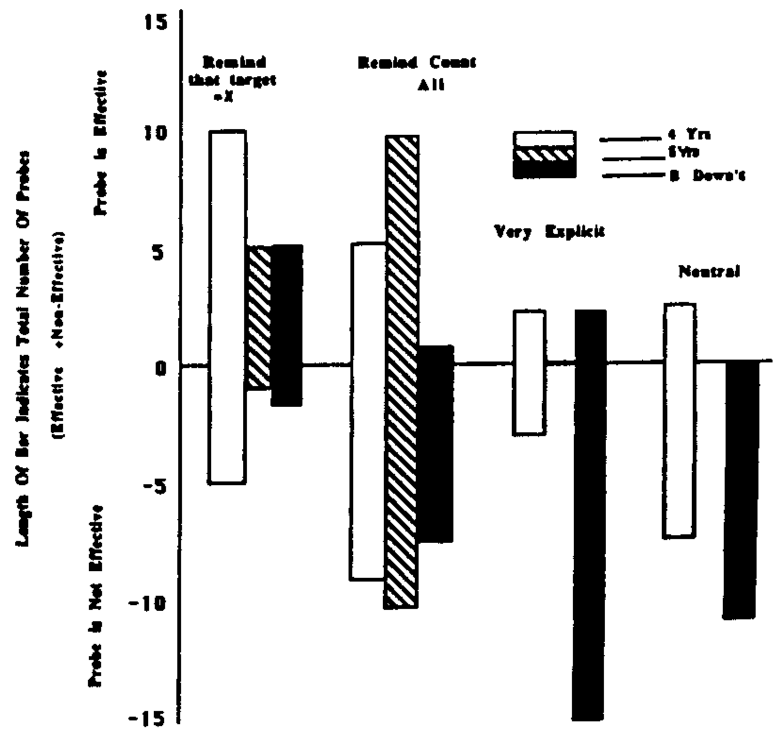
Figure 6. Mean number of experimenter's utterances between a child's first and final attempt to assign a given item the target counting tag.



Notice that the DS children seldom repeated a trial on their own. In fact, 80% of the time that the DS children did repeat a trial they did so because of something the experimenter did first. Further, we can show that the experimenter had to work much harder to get DS children to initiate a repeat of the trial. This is clear even if we simply consider the amount of talk an experimenter produced between a child's first and final effort.

Fig. 6 shows that Group B DS children heard an average of about eight adult utterances per target trial. No oth-

Figure 7. Kinds and effectiveness of hints given between a child's first and final attempt on a given trial of the task. Very explicit hints could take the form of instructions or demonstrations. Neutral hints were ones like "Do you want to try that again?".



er group heard even half this much talk! Additionally, as can be seen in Fig. 7, none of the other groups received as much explicit help. Fig. 7 summarizes the kinds of hints children received and the extent to which a given kind of hint was used effectively. The rate at which the kinds of hints shown in Fig. 7 were offered is reflected in the total length of a given bar. For example, 5-year-olds encountered relatively few reminders that they were to assign a given tag to a given object.

It is important to realize that we scored a child as receiving a hint no matter how long the utterance. This means that Fig. 7 is a conservative way of illustrating the amount of help we gave the DS children. Yet, it is clear that it was the preschool children who were most likely to benefit from our hints. The effectiveness of a particular kind of hint is captured by the height of that bar. The extent to which the same kind of hint was or was not effective is captured by the length of portion of the bar that is above or below the horizontal axis.

Since most of the bars of the DS children are below the horizontal axis, we can conclude that they benefitted the least from the tendency of the experimenters to lend a helping hand. This overall effect supports the idea that these children were not working with a principled understanding of counting. Not only is it the case that these children did not self-initiate their follow-up efforts, even when given hints as to what to do, they failed to benefit from these hints, -- even when they were extremely explicit. The following protocol excerpts illustrate both kinds of explicit help they received and how little effect it had.

[Subject A, DS Group B]
(x = 4 trial)

Experimenter: Make the scissors the 4. (Scissors are in the middle position.)
Child: (Starts by tagging the target item.) 4, 5. (He pauses at length after saying 5 and puts his hand on his head.)
Experimenter: What's wrong?
Child: I don't know.
Experimenter: Okay, let me show you another way to do it, okay? You can go like this. (The experimenter demonstrates.)
Child: (Counts along with experimenter who points to the objects.) 3, 4, 5.
Experimenter: You don't have to count them all in order. Okay, and another thing, if you want to move these scissors (points to target), you can do that. You can move them anywhere you want. Okay? So do you want to make it number 4 now?
Child: (He counts slowly across the array from left to right, hesitating slightly before saying 4.) 1, 2, 3, 4, 5.
Experimenter: Okay, now this time make them (the scissors) number 4. The last time you made them number 3. Make them number 4.
Child: (Counts from 1 to 5 skipping over the target but returns to tag the target as 5 rather than 4.)
[Experimenter goes to x = 5 trial]

(x = 5 trial)

Experimenter: Make the scissors the 5. (Scissors are in the middle position.)
Child: (Starting with the leftmost item, the subject counts.) 1, 2, 5. (He pauses before saying 5, then holds his head in his hand.) Oh boy.
Experimenter: You want to start over?
Child: Yeah.
Experimenter: Let's see you make them number 5.
Child: (He proceeds to count again from the left) 1, 2, 3. (He pauses after 3 and again holds his head with his hand.)
Experimenter: Okay, you can skip it. Do you want to just skip it? Okay, number 5 (points to target) and when you get to 3 you just jump to the purse. Okay, let's start over.
Child: 1, 2, 3, 4, 5. (He proceeds correctly, following the explicit instructions of the experimenter.)

[Subject B. DS Group B]
(x = 3 trial)

Experimenter: Make the candle the 3. (The candle is

the second item from the left.)
Child: (Pause) What? (Starts to count from the candle, the target item, tagging it 1 and continues) 2, 3. That's 3. (The item tagged 3 is actually in fourth position.)
Experimenter: Okay. This time make the candle be number three. When you get to number three, call the candle number three.
Child: (Nods yes. Pause.)
Experimenter: Okay, try that.
Child: Three?
Experimenter: Uh huh.
Child: Okay. (Child produces an exact repeat of the first attempt.)
Experimenter: Okay. Can you make the candle be number three this time?
Child: Yes. (No response.)
Experimenter: You made the mirror be three; I want you to make the candle be three.
Child: (Pause.) One?
Experimenter: Make the candle be number three okay? Start somewhere and start counting. Then when you come to number three (Experimenter points to the target while saying three.) point to the candle. You can move the candle around if you want. You can move the candle out (Experimenter demonstrates.)
Child: (No response.)
Experimenter: However you want to do it, okay, you try it.
Child: Me?
Experimenter: Yeah.
Child: I try it?
Experimenter: Uh, huh. Go on.
Child: What?
Experimenter: (Points to the candle) Make the candle be number three. [Eight further exchanges like these occurred before the child finally tried to deal with the task, again unsuccessfully.]

The above interactions between an experimenter and a given DS child contrast dramatically with the kind that occurred between an experimenter and a preschool child. This is illustrated in the following transcript excerpts

of the protocols from the preschool study. Note the absence of both explicit hints as to what to do and any of the kind of modelling of solution types that is part of the above interaction between an experimenter and the DS child.

[Subject #4 (4 years, 2 months)]
(x = 4 trial)

Experimenter: Make the strawberry the 4. (The strawberry is in the second position from the left.)
Child: 1, 2, 3, 4, 5. (He counts across from left to right.)
Experimenter: You just made the strawberry be number 2. Can you make it be number 4?
Child: (He counts starting with the leftmost item, skips over the target, and continues counting to the end of the row. He then skips back to tag the target as 5.)
Experimenter: Can you make the strawberry be number 4?
Child: (He now starts again with the leftmost item, skips over the target to tag the next two items (in the third and fourth positions) as 2 and 3, and returns to the target, tagging it as 4.)
Experimenter: Did you get everything?
Child: I didn't get that. (He now self-corrects but just repeats what he did on his second attempt at this trial.)

[Subject #6 (4 years, 3 months)]
(x = 1 trial)

Experimenter: Make the bee the number 1. (The bee is in the second position from the left.)
Child: (she counts from right to left from 1 to 4, stopping after tagging the target as 4.)
Experimenter: I said to make the bee the number 1.
Child: (She now performs perfectly on this trial by skipping among the items.)

[Subject #7 (4 years, 5 months)]
(x - 5 trial)

Experimenter: Make the balloon the number 5. (The balloon is in the middle position.)
Child: (He tags the second item from the left as 1 and pauses. He then repeats himself but continues by tagging the leftmost item as 2, and then the target item as 3.)
Experimenter: (Interrupts the child.) I wanted the balloon to be number 5.
Child: (He now performs perfectly on this trial by skipping the target item and returning to it to tag it as 5.)

[Subject #11 (4 years, 7 months)]
(x - 3 trial)

Experimenter: Make the (target item) the 3. (The target is in the second position from the left.)
Child: Can this be number 2? (Points to the middle item.)
Experimenter: Whatever you want.
Child: (She starts by tagging the leftmost item as 1, skips over the target tagging the middle item as 2, and returns to the target to tag it as 3. She then pauses.)
Experimenter: Did you get them all?
Child: (She continues her count, tagging the remaining two items as 4 and 5. The trial is thus completed correctly.)

[Subject #27 (5 years, 6 months)]
(x - 4 trial)

Experimenter: Make the bone the 4. (The bone is in the rightmost position.)
Child: I'm thinking about how to do his. (He hesitates for a long time then counts the items to himself.) I can do it if I move the bone to where the strawberry is (Second position from the right). (He then switches the two items creating a correspondence between the items in the array and the words in his count list. He counts, beginning with the leftmost item and counting across to the right tagging the items from 1 to 4.)
Experimenter: Did you get everything?
Child: (He points to the rightmost item which has not yet been tagged and says 5, thus correctly completing the trial.)

[Subject #28 (5 years, 7 months)]
(x - 5 trial)

Experimenter: Make the (target item) the 5. (The target is in the middle position.)
Child: (She hesitates before starting, tags the rightmost item as 1 and stops.)
Experimenter: We want this one (points to the target) to be number 5.
Child: (She now performs perfectly on this trial by starting to count from the rightmost item, skipping over the target when she gets to it, and returning to the target to tag it as 5.)

[Subject #31 (5 years, 9 months)]
(x - 3 trial)

Experimenter: Now, make it (target item) the 3. (The target is in the leftmost position.)
Child: (He starts with the second item from the left and tags as 1. He continues to the right with 2, 3, 4, and returns to the leftmost item to tag it as 5.)
Experimenter: Can you count them and make this be number 3?
Child: (He begins again with the second item from the left and tags it as 1. He next tags the middle item 2 and returns to tag the leftmost item 3. The trial continues with the child tagging the rightmost item as 4 and the item to its left as 5. The result is a perfect performance on this trial.)

The preceding protocols help illustrate another feature of the results plotted in Fig. 7. Normal preschool children received the kind of input our design called for, that is neutral statements or reminders regarding the constraints of the task. As regards the latter, these children, especially the 4-year-olds, had a tendency to ignore the task constraint that they use a particular count word for a particular object. Hence, they received a total of 15 reminders about this. Similarly, the preschoolers had a tendency to forget that they were to do this and yet count all of the set. So they heard the experimenter say things like "Did you count all of them?"

Overall then, the results graphed in Fig. 7 indicate that DS and normal children were likely to receive different kinds of hints. Normal preschool children were typically reminded about some constraint of the task or simply encouraged to start over. Often as not, these hints led to improved performance levels, despite the fact that the experimenter did not provide explicit suggestions as to how to improve. In contrast, DS children were most likely to receive very explicit hints, which included demonstrations of what to do. Nevertheless, such feedback was not especially effective. This is exactly the pattern of results we indicated one should see if normal children were able to benefit from implicit principles and DS children were not. To repeat, we pointed out that children who already have some implicit knowledge of the counting principles have the wherewithal to recognize -- on their own -- their mistakes, to start over, and to benefit from subtle hints. Children who are not able to take advantage of such a supporting mental structure have no resources other than those provided by others (cf. Brown & Reeve, 1987). Worse yet, even when those resources are presented to them, they are at risk because they may fail to recognize the resources for what they are worth -- just as some of the DS children failed to benefit from explicit clues regarding a solution path.

Further Evidence: Differences in Error Types and Flexibility - Recall that one need not use the conventional count words of a given language in order to honor the counting principles. But one cannot double tag items or omit items in a set and still honor the principles. Given these considerations, children who do have implicit understanding of counting principles might be more willing to alter the nature of the tags they use than to violate basic constraints of the one-one principle. Our first hint that this is indeed what some preschool children did

came from our observation that some of them solved the constrained counting problem by tampering with the conventional order of the count list. For example, one child met our request to make the second item from the left end of a row "the three", by tagging the items left to right while saying "1, 3, 2, 4, 5". To be sure, this solution does violate the stable order principle. However, it honors the one-one principle, a principle that one may want to grant a special status given its mathematical import (See Greeno et al., 1984, for a discussion of the mathematical significance of the one-one principle). If so, children might be expected to tolerate errorful plans that violate their rote knowledge of the conventional counting list if it means that they will still honor the one-one principle -- assuming of course that they know they should honor this principle.

To assess the merit of the foregoing line of reasoning, we reviewed the transcripts of individual children to see whether they had inclinations to alter the conventional count list order and if so, what sorts. For this analysis we considered the expanded "doesn't matter" data base we had for the children. We did this in part because the analysis depends on children making errors. Therefore we looked at the responses the DS children made with heterogeneous displays of either five or eight items. In the case of the preschool children, we also looked at their answers when the displays were arranged in circles.

None of the DS children in Group B varied the conventional order of the counting words. Most of the time, this means that they made one-one errors instead. The only way to avoid making one-one errors and still stick to the conventional order is to start a tagging sequence with the target and it's requisite tag. Thus, for example, a child who was asked to make a given item "the three" did just that. She pointed to the item in question and said "3" and then continued to count, thereby producing the count word string "3, 4, 5, 6, 7, 8" while tagging the items. In fact this same child continued on the next trial to make the same item "the four" by counting "4, 5, 6, 7, 8, 9", an outcome which means her successive counts could not serve as evidence that the cardinal value of a set is conserved over count trials.

Both groups of preschool children were less inclined than were DS children to adhere strictly to the conventional count-list order. Although the preschoolers did make some effort to honor the conventional count list order on their error trials, they also were willing to alter the order, and thereby avoid violating the one-one principle. Of the 16 and 14 4- and 5-year-olds, respectively, who made any errors at all, 44% in each age group showed at least some inclination to alter the conventional counting order.

It is especially interesting that there is no age difference here. For the 5-year-olds surely had more reinforcement for using the conventional list than did the younger children. On a strict associationist account, they should have been more inclined to stick to the conventional count list order. That they did not is consistent with our hypothesis that our preschoolers, unlike Group B DS subjects, were able to put principle ahead of habit -- at least some of the time. So is the fact that some of these young children laughed, or made it clear they were "fooling" or joking when they made errors that seemed to serve the purpose of meeting task constraints. (The extensive counting training offered to our DS subjects might account for the fact that even our two excellent counters maintained a consistent sound word order when they started to make errors, especially on their trials with 8 items.)

The preceding results add weight to our conclusion that the majority of DS children actually did learn to count by rote and that, despite the benefit of a curriculum that is designed to give them a great deal of counting experience, they did not induce the principles that govern counting. Indeed, if anything, this kind of rote learning seems to have produced less flexibility, a conjecture that is supported by the kinds of data Wishart (this volume) presented on the way DS infants deal with the object concept task. It also gains support from one further consideration of the preschoolers' performances.

As discussed in the Section - Procedures, circular displays present a special problem to children should they think they are to recite a list of count words until they come to the end of a row. Unless they are able to take into account their initial starting position and then use this to signal when to stop reciting count words, they

run the risk of continuing on and on and on. One clear sign that our preschoolers did not do this comes from the fact that they did better on their circle trials than their line trials! Whereas five children in each of the age groups turned in perfect performances on their circle trials, only 3 of the 5-year-olds did as well on their linear displays. This is hardly what one would expect if the children who are used to counting items in rows have learned to do so without considering the demands of the one-one principle. Indeed, given that children did somewhat better with the circular arrays, we can conclude that they were able to honor the one-one principle in a flexible way.

Summary of Differences - We have presented a variety of findings that all converge on the conclusion that normal preschool children are not only better able to deal with a novel counting task; they approach the task of generating novel solutions in ways that are qualitatively different than those used by all but two of our Down Syndrome children. They are much more inclined to self-correct their false starts, to understand subtle hints, and to vary their solution types as their target instructions and stimulus conditions vary on them. Further, when they do make errors, they are willing to alter the order of the tags in the standard count sequence, a fact which makes them less likely to violate fundamental counting principles, as compared to the majority of the DS children. The DS children seem not able to benefit from hints as to how to solve their novel problem, even when these hints include explicit instructions or demonstrations of possible solutions. Their patterns of responding are consistent with the hypothesis that their learning to count was controlled by a rote, associative learning process. Since the normal children's patterns of responding are so different and fit well with the predictions made by a principle-first learning model, we conclude that qualitative differences in their favor are due to their being able to take advantage of a skeletal set of the counting principles, ones which enabled their novel generation of counting solutions for the Constrained Counting Task.

On Inferring Causality: Proceed with Caution

We have shown that most of the DS children in this study fit the associative learning model: In contrast, the responses of the normal preschool children to our novel counting task are better described by the principle-guided learning model of counting knowledge. Given this, we can say that normal children are privileged insofar as they are able to take advantage of a set of counting-relevant principles in order to generate acceptable responses even when confronted with a novel task. They are also able to make sense out of subtle hints, the ones that offer little, if any, guidance as to how to correct an errorful plan. Also, they seem motivated to stick with a problem until they find a way to solve it. These results are buttressed by the findings that show that, all over the world, individuals invent counting solutions to solve arithmetic problems confronted in their everyday lives, whether or not they have had any formal schooling (e.g., Carraher, Carraher, & Schliemann, 1985; Lave, 1977; Posner, 1982; Scribner & Cole, 1973). Together, these findings converge on two clear conclusions: First, normal individuals are able to assimilate whatever mathematically meaningful inputs they encounter, and can do so, as it were, on the fly. Second, they can generate solutions to some problems, even if they have not been given guidance on the matter, in either a hinting or more direct fashion. These conclusions fit very well with the rational constructivist account of the acquisition of counting knowledge. They are not so obviously consistent with the associationist account.

Although we are able to reach the foregoing conclusions for normal children, we cannot conclude that DS children lack an initial skeletal base of counting principles by dint of their genetic history. Indeed, it is not clear that we can conclude they totally lack the initial benefit of some skeletal set of counting principles. When we introduced our research plan we were careful to point out that should we find that DS children actually produced qualitatively different solutions than normal preschool children, we would not have license to attribute the difference to the genetic variables known to contribute to

Down Syndrome. As has been discussed elsewhere in this volume, there is a wide range of variables that need to be considered even if we should find that it is only DS children who differ as described here from normal children. And, of course, it is necessary to determine whether similar results would obtain for children who suffer from other kinds of mental retardation. Baroody's (1986) study of counting abilities in mildly retarded children highlights this possibility. It is also necessary to consider whether the same findings would hold were the DS children offered a different curriculum.

Are the Results Counting Principle Specific? - Assuming that we could determine the range of variables that control the described differences, we still must ask whether we can ascribe the differences to the presence or absence of an initial base of implicit counting principles. One clear possibility is that the difference is due more to the DS child's difficulty in learning to map mathematical symbols to underlying principles. The evidence is mounting that a variety of nonverbal organisms can count in a principled way (Gallistel, in press, for a review). An obvious way in which the human ability to count differs from that of animals has to do with their ability to master a mathematical symbol system that captures the nature of these principles. Given that DS children's ability to master another symbol system, that described by linguistic principles, is limited, we must consider the possibility that they are at risk in general when it comes to mastering symbolic material in a principled way. It is therefore entirely possible that DS children do have some early, implicit understanding of some counting principles but fail to develop them because of limits on their abilities to master the mathematical meanings of count words and other mathematical symbols, a task that we are beginning to see is exceedingly complex and difficult for all (e.g. Gelman & Greeno, in press; Resnick, 1987).

A Return to the Two Models and Some Pedagogical Considerations - We began with the idea that comparative research can offer insights about the nature of human cognition. Our comparisons of the ways the DS and normal preschool children solved the constrained counting task support the conclusion that normal individuals benefit from the availability of counting principles from the outset, ones that support the acquisition of counting knowledge and the generation of novel solutions. Surely the reader is wondering whether it is impossible to arrive at a principled understanding of counting without having started with some skeletal outline of it. We think not. Instead, we prefer to say that the path to such knowledge is ever so much more treacherous when one cannot take advantage of such principled help. With such principles on hand, children can find their way through ambiguous environments for they have guidelines as to which inputs fit the equivalence class that is relevant to the learning. Even if we as teachers fail to present the data base in a way that would best nurture development, children have going for them an inclination to both use and extend their existing knowledge structures. These in turn provide ways of both collecting and storing a coherent set of relevant inputs. So even if these inputs are few and far between, disorganized, and dressed up with irrelevant details, the mental structures can serve to filter the good from the bad. Children who learn only as associationist theorists say they do, are at a disadvantage because they are especially dependent on others to structure their inputs. Put differently, it becomes especially important to develop teaching methods that package inputs in ways that might be expected to support mathematical inductions. From our perspective, there is one clear educational implication of this consequence. We must arrange our teaching materials so that they are congruent with mathematical principles. Instead of drilling children in the count word sequence, we might better turn our efforts to teaching them that count words are only tags, that count words acquire their meaning when they are used in ways that are consistent with the counting principles, that it is not necessary to count from one end of a row to the other, and it does not matter what items are collected together for a count. It is a tall order for sure, but one we might try before deciding it cannot be met. To those who counter that the children should not be asked to deal with matters pertaining to the counting principles unless they have mastered the conventional count list, we respond: What about the 4-year-old children in our study who probably were less practiced on the count list?

Acknowledgments

The research presented in this chapter was supported by NICHHD Program Project Grant No. P01 HD-10965 to David Premack; Deborah Kemler and Rochel Gelman and NSF Grant BNS 85-19575 to Rochel Gelman. It is based in part on Melissa Cohen's senior honors thesis and in part on a paper presented by the first author at the conference reported in this book. We are especially grateful to the parents and children who came to our lab and the children, parents and staff affiliated with St. Katherine's Day School, the Paley Day Care Center, and the Bankcroft School for offering their cooperative participation in our work. Thanks also to Michael Siegel and C.R. Gallistel who read and made comments on earlier versions of this paper.

Footnotes

1. David Premack organized a group of us to do comparative studies with chimpanzees, normal and/or retarded children. In addition to Gelman and Fowler, the group has included Lila Gleitman and Deborah Kemler and students or visitors working with one or more of us.

2. We included sessions with 5 and 8 homogeneous items because we thought children would be forced to move the target item so as to mark its special status. Given they did even more poorly under these conditions, there will be no further mention of them.

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