The Developmental Psychology of Time

EDITED BY

William J. Friedman

Department of Psychology
Oberlin College
Oberlin, Ohio

1982

ACADEMIC PRESS

A Subsidiary of Harcourt Brace Jovanovich, Publishers
New York London
Paris San Diego San Francisco São Paulo Sydney Tokyo Toronto

PP1 (30).max

Merry Bullock
Rochel Gelman
Renée Baillargeon

The Development of Causal Reasoning[1]

For the world mankind has hacked out of chaos—all science, art, religion, and indeed civilization itself—depends for its existence on the basic limiting principles: that no effect can precede its cause, that effects must be physically related to causes, that cause and effect if separated in space must also be separated in time, and that mind cannot operate independently of brain.

John Gardner, *The Resurrection*[2]

INTRODUCTION

Our understanding of the physical world and, in particular, of the changes—the displacements and the transformations—that take place within it, rests in large part on our ability to group temporally successive occurrences into coherent units. The world does not appear to us as an ever-changing stream of coincidental, arbitrary occurrences. To the contrary, our perceptions, memories, and descriptions all tend to be of events occurring in organized patterns (cf. Mandler, 1980; Neisser, 1976; Schank & Abelson, 1977) over specific time courses (Gibson, 1980).

How do we establish the boundaries of events? It is clear that the perception of discrete, temporally bounded events requires "bracketing" simultaneous and/or successive occurrences together. A fundamental basis for this partitioning is provided by our tendency to perceive or infer cause–effect relations.

[1]This work was supported by NIMH predoctoral fellowship 1-F31-HD-05588 and SSHRC general grant to UBC, 66-3157 to M. Bullock; NICHHD grant No. HD-10965 and NSF grants No. BNS 770327 and 80-40573 to R. Gelman; and Quebec Department of Education grant to R. Baillargeon.

[2]Reprinted from *The Resurrection*, copyright 1966 by John Gardner. Reprinted with permission of the author.

Copyright © 1982 by Academic Press, Inc
All rights of reproduction in any form reserved.
ISBN 0-12-268320-X

PP1 (30).max

Consider the act of cutting bread. This could be described simply as two interlocking sequences of knife movements and bread movements, occurring over time. However, because we regard the parting of the bread to be *caused by* the knife's action, we perceive not a succession of separate, coincidental movements, but one event, a knife cutting bread. This example illustrates two points. First, by imposing a causal connection, we efficiently collapse a series of temporally successive motions into a single event. Second, by this bracketing into causal events, we not only separate meaningful, coherent patterns from all that goes on around us, but also impart structure to the world. When we attribute the parting of the bread to the knife's action, we relate actions to results, transformations to outcomes, and thus construct our own physical reality.

A tendency to relate events causally underlies much of the learning during development, especially concerning the physical world. We learn how the objects around us characteristically work, and we use this knowledge to predict, influence, and eventually explain those actions. We learn what transformations can be applied to what objects, with what likely outcomes, and again use this knowledge to bring about desired ends or avoid undesirable ones. We could describe this learning by saying that we discover relations between objects or occurrences in time. In this sense, our understanding of events would be derived from a representation of the temporal sequencing of particular instances. However, the notion that we frame events in terms of causal relations implies that our representations of temporal sequences are mediated by an understanding of cause-effect relations. That is, the "limiting principles" specified by John Gardner in the epigram may influence how the temporal flow of occurrences is parsed, interpreted, and understood.

In this chapter we will consider how children apply causal understanding to physical events in time. We will address two related questions: (*a*) How does a causal framework operate? (*b*) How does it develop? Since models in developmental psychology must ultimately make reference to how we as adults operate in the world, we begin with a model of adult causal thinking—one that we believe captures the ways in which adults reason about everyday events. After we review the extant literature in light of this model, we present recent experimental evidence that suggests that children as young as 3 years of age relate physical events in much the same manner as adults. In addition to an analysis of the nature of causal understanding, the studies we report address the general methodological issues of assessing the thinking of young preschoolers.

A Characterization of Causal Reasoning

We present below a "common-sense" model of the organization that seems to underlie our everyday ideas about cause and effect. We believe the adult's understanding of causal events is constrained by a small set of assumptions, or principles, which not only define what could constitute a causal event, but delimit as well the type of information adults look for or consider when making causal attributions. Although there may be overlap in application in this model, we distinguish conceptually between *principles* underlying the definition of cause and effect, *stimulus information* used in making causal attributions, and the role of general *knowledge* about objects in causal attributions and causal explanations.

CAUSAL PRINCIPLES

At least three separate principles underlie an adult's definition of cause-effect relations. A first principle is *Determinism*. Adults typically assume that physical events are caused, so they are reluctant, if not unwilling, to allow causeless occurrences. Imagine, for instance, a window shattering. We are likely to believe someone or something caused the window to break, even if we cannot identify who or what it was. We might be forced, in other words, to confess ignorance of the precise *identity* of the cause of the shattering, but we are not likely to doubt that it exists.

A second principle, that of *Priority*, concerns the temporal ordering of causes and effects. For adults, the causal relation is always unidirectional: causes precede or are coincidental with their effects. In our example of a window shattering, adults would consider *only* events that occurred prior to the breakage when searching for a possible cause. Events that followed would simply not be admitted as candidate causes.

We include a third principle, *Mechanism*, as central to the psychological definition of cause-effect relations. Adults typically assume that causes bring about their effects by transfer of causal impetus, effected directly (e.g., two billiard balls colliding), or through a chain of intermediary events (e.g., starting the engine of a car). This assumption leads adults to look for antecedents that they know, or at least suspect, *could* have produced the phenomenon to be explained. Thus, in the case of the shattered window, we would search for objects (e.g., a bullet, a boomerang, a chair) whose impact we knew might have broken the glass; conversely, we would ignore objects (e.g., a feather, a sponge, a pin) whose lesser impact would surely have left the window intact. It is important to note that this attitude can lead to the selection of real or imagined events, including supernatural ones.

The adult's assumption and use of the principles of determinism, priority, and mechanism need not imply that the world operates according to these or even similar principles. The veracity of a determined, temporally bound, mechanistic universe is an issue debated by both philosophers and physicists. Still, we claim that these principles are an essential part of an adult's *causal theory* or *causal attitude*, and as such contribute to the structuring and interpretation of events.

PP1 (30).max

While the principles of determinism, priority, and mechanism constrain causal attributions, they do not in themselves specify the causes of events. The choice of which of a set of possible causes led to a particular outcome must ultimately depend on what an individual understands about the events involved. This may include a general knowledge of the kinds of transformations that occur in the physical world, as well as specific information about the particular events. The role of knowledge will be considered in a later section. We turn now to the role of stimulus information.

THE ROLE OF STIMULUS CUES IN THE SELECTION OF CAUSES

The ways in which causal judgments are affected by stimulus cues can be illustrated most clearly in a case where adults do not have complete knowledge of the phenomenon to be explained.

Say we are shown a large covered box, told it contains a bell, and asked to decide which of three marbles made the bell ring. The first marble is dropped through a hole in the top of the box, a few seconds go by, and then the remaining two marbles are dropped, one through the hole, the other next to the box. A second or two later the bell rings. Our most likely answer in this situation is to say the second marble dropped inside the box was the cause. This marble was dropped immediately prior to the bell's sound, and it went inside the box, making physical contact between marble and bell possible. Now it could easily turn out that the first marble dropped was in fact responsible for the ringing of the bell—if, for example, some complex, slow-moving mechanism had been activated which resulted, many seconds later, in the bell ringing. Clearly, the probability of a *correct* causal attribution is lower when only temporal and spatial cues are available. Still, a reliance on the cues of temporal and spatial contiguity serves as an excellent rule of thumb since in many causal sequences causes *are* found to be temporally and spatially contiguous to their effects. Given this, it comes as no surprise that temporal and spatial continguity have been shown to be particularly important for generating "causal perceptions" in adults. Michotte (1963) and others (Gruber, Fink & Damm, 1957; Olum, 1957) demonstrated that adults will have a strong, direct impression of a causal connection between events when these cues are provided, even when they know the connection is in fact illusory.

Adults do not, however, rely on temporal and spatial cues only when they lack knowledge relevant to a particular situation, or when confronted with schematic sequences such as those devised by Michotte (1963; Bassili, 1976; Olum, 1957). Adults also use information about relative contiguity to decide among different potential causes. If two rocks were thrown at our window, one after the other, but both before the window shattered, we would probably consider as cause the one

PP1 (30).max

that arrived at the window just before it broke. In other words, given two plausible causes (either rock could have broken the window), we would select the one immediately prior to the effect as the cause. It is important to realize that our use of temporal contiguity may be mediated by our general knowledge of rocks and windows (i.e., windows shatter immediately upon impact). Had we been told that the particular window in question shattered no sooner than three seconds after impact, we might have chosen differently. Similarly, spatial contiguity may help decide between two plausible causes. We will be most likely to pick the one closer in space to an effect, unless we know of some reason why this cue might be misleading (magnetic or electrical phenomena come to mind here). The use of spatial and temporal information is in accordance with the principles previously outlined. The assumptions of priority and mechanism allow us to use the temporal and spatial relations among events to decide among possible causes.[3]

Another source of information about possible causes comes from the contingency relations between events. Covariation of one event with another, or the marked regularity with which events co-occur, is likely to lead us to suspect a causal connection (see the literature on attribution theory, especially Kelley, 1973; Nisbett & Ross, 1979, for more detailed discussions of covariation and sufficiency arguments). Covariation and contingency information are important for causal attributions made over a number of experiences. However, they neither speak to how we form a causal impression in the single case, nor to how we learn about causal transformations in general. We will return to the use of contingency information in our concluding discussion when we consider the role of necessary and sufficient conditions in providing explanations for events.

THE ROLE OF KNOWLEDGE IN THE SELECTION OF CAUSES

An adult's choice of a cause is constrained by the principles which mediate the interpretation of stimulus information. Further, it is influenced by two sources of knowledge. One is specific and concerns the types of events involved; the other is more general and concerns an understanding of transformations over time.

To illustrate the role of specific knowledge, the choice of a cause for our familiar broken window will depend in part on such things as knowledge of the brittleness of glass, the force of impact, and so on. If this knowledge is incomplete, the range of possible causes will be restricted. An individual who did not

[3]We are ignoring, for this discussion, instances that may be labeled "over-determined," and are assuming a choice of one cause. There are of course exceptions to this. Say two bombs hit a target within seconds of each other. Either alone could have caused the resulting explosion, thus both could be causes, and the *relative* temporal or spatial information is not relevant. In other words, both are sufficient causes, and it is likely that we would say that both bombs were causes. However, in many everyday events with these same properties, we do tend to identify single causes, even at the expense of oversimplifying the matter.

know that sound waves exert force would most likely (and perhaps mistakenly) reject the notion that a sonic boom or Ella Fitzgerald's voice could ever be responsible. Similarly, if asked whether an "irredentist" was the cause, we would be uncertain until we knew what an "irredentist" was, or at least what *type* of thing it was. The nature and extent of one's knowledge about the physical world thus plays a central role in determining which antecedents one will allow to play a causal role.

Related to our tendency to bracket events in terms of causal relations is a more general ability to track objects through time and over transformations. Framing events in causal terms imposes a unidirectional relation over time. This relation may be described in terms of cause and effect, or in terms of a transformation that has changed the state of some object or event. The unidirectionality of causal sequences implies that the transformations they embody are also unidirectional. For example, while a rock's action may transform a window, the window's shattering does not cause the rock to move. To understand events in this way, one needs to be able to relate object states to each other, infer the connecting transformations, and distinguish the direction of transformations.

CAUSAL UNDERSTANDING AND CAUSAL EXPLANATIONS

It is necessary at this point to distinguish two senses of causal knowledge. In one sense, knowledge can be explicit, accessible, and articulable. In this case, we gauge how someone understands an event by what he or she says about it. The person who declares "causes precede effects," for example, has an explicit knowledge of at least one of the defining criteria of cause.

In a second sense, an individual may be said to possess knowledge about an event when she or he treats it in a principled, consistent manner. This more tacit knowledge can be detected through its systematic influence on behavior. It need not be accessible to conscious reflection and may not be articulated in causal explanations. We need not, for example, be able to articulate the fact that priority is a causal principle to only pick prior events as causes.

The relation of causal explanations to the senses of understanding just outlined is not direct. We may possess principles defining cause and effect, we may use stimulus information in a particular way, we may be able to relate object states and transformations in time; yet, explanations require something more: we must understand *what* an explanation entails. While statements given in answer to "Why did it happen?" may range from a restatement of the phenomenon ("*It fell*"), to identification of a salient feature of the event ("*It wasn't nailed in too well*"), to complex chains of interpolated causal mediation ("*The picture fell off the wall because vibrations from the jack hammer sent shock waves through the foundation, up the walls, across the beams, and caused the wire to jiggle and break*"), in general we accept as more adequate those explanations that make

PP1 (30).max

reference to some implied or demonstrated mechanism, indicating *how* a cause brought about its effect rather than the fact that it did so. We might expect, then, that the quality of explanations will depend on our interpretation of the question asked, the ease with which we can postulate the nature of a mechanism, and the extent to which we understand that explaining is different from restating an event.

Developmental Evidence

In distinguishing causal principles, information about the stimulus environment, and general knowledge, we have implied that the principles are fundamental to the structuring of causal reasoning, constraining the uses of stimulus information and general knowledge. The ontological questions then are: How have the principles arisen, and do they change over development? We may conceptualize at least three distinct models that address these issues.

A first model, one most directly related to the empiricist philosophical approach (cf. Hume, 1748/1955), postulates that the principles underlying adult causal thinking are abstractions from repeated experience with the world. This model could take different positions on how the principles are abstracted, from simple associations (cf. Kendler & Kendler, 1975) to the detection of event invariances (cf. Gibson, 1966), but it would claim that the principles underlying adults' causal reasoning are derived from, not responsible for, the structuring of events.

A second approach, one more related to a structuralist philosophical stance (cf. Kant, 1787/1965), reverses the relation between stimulus information and principles, and postulates that the principles reflect a prior organization that the mind imposes on experience. This second approach provides two models. In one, the organization that the mind imposes on experience is seen to change with development; thus, children's thinking should be characterized by a different set of principles than adults'. In the other model, the organization underlying causal thinking may remain constant throughout development, but may be only imperfectly reflected in children's reasoning because of performance limitations.

Developmental researchers have not, by and large, explicitly acknowledged these models. However, the extant literature may be roughly divided into those studies that have focused on the use of stimulus information, and those that focused on characterizing underlying principles or organizaiton, allowing us to categorize them along the empiricist and structuralist lines. We shall categorize our brief review of the literature accordingly. First, we consider those studies that address the issue of the use of stimulus information: What cues do children notice? How is stimulus information combined? and How is children's use of information limited or different from adults'?

EMPIRICIST STUDIES

While it is generally agreed that even young children use temporal information, specifically temporal contiguity (e.g., Kuhn & Phelps, 1976; Shultz & Mendelson, 1975; Siegler & Liebert, 1974; Wilde & Coker, 1978), there is disagreement over whether children are limited to the use of *only* temporal contiguity. For example, both Shultz and Mendelson (1975) and Kuhn and Phelps (1976) presented evidence suggesting that initially children were as likely to pick subsequent events as antecedent events when asked for the cause of a particular occurrence. This research suggested that while contiguity information was used, children did not understand the unidirectional nature of the cause-effect relation. Kun (1978), however, has shown that preschoolers *will* use order information when judging picture sequences of activities. Similarly, others have argued that even very young children's representations of events include order of occurrence (e.g., Brown, 1975; Copple & Coon, 1977; Mandler, 1980).[4]

Spatial cues also affect children's attributions under some circumstances. Mendelson and Shultz (1976), for example, reported that preschoolers were more likely to pick a temporally contiguous but inconsistent event as cause over a consistent, noncontiguous event unless there was a spatial connection (or contiguity) between antecedent and effect. Similarly, Lesser (1977) and Koslowski (1976) both reported that preschoolers were *less* likely to pick a spatially removed event as cause. Although these studies are primarily suggestive about the role of spatial information, they do indicate that spatial information may, in some circumstances, be used in causal judgments. Wilde and Coker (1978) found that children as young as 3 required spatial contiguity between cause and effect for events that involved motion or hitting (such as moving blocks).

Children's use of stimulus information other than contiguity, particularly the covariation of events, seems to be affected by both the complexity of the events and the child's prior knowledge. Preschoolers (3-4 years of age will select, as cause, an antecedent that consistently co-occurs with an event over another antecedent that occurs less regularly (Shultz & Mendelson, 1975; Wilde & Coker, 1978). However, the influence of covariation information is more limited in younger children's attributions, especially if they must extract it over a time delay or if it contrasts with contiguity information (Siegler, 1975; Wilde & Coker, 1978). Siegler presented children aged 5-9 with a choice between a temporally contiguous but inconsistent cause (a computer whose lights flashed on and off), and a cause that regularly preceded the effect by 5 seconds (the insertion

[4]The researchers claimed they were investigating order cues. However, in terms of our model, it is possible that children's responses were constrained by the priority principle, thus making the use of order cues a matter of course. This argument may also be applied to the cue of spatial contact versus the principle of mechanism.

PP1 (30).max

of a card into a sorter). Older children picked the regular event as cause; younger children were more likely to pick the continguous event.

Wilde and Coker (1978) have similarly reported that while all their 4- to 8-year-old subjects used temporal and spatial contiguity cues, only the older (6 and 8 years old) children's attributions used covariation information when it contrasted with contiguity information.

Several investigators have suggested that children's use of stimulus information is influenced by their familiarity with or general knowledge about the events they witness. Ausubel and Schiff (1954), for instance, had children learn to predict which side of a teeter-totter would fall when its supporting pins were removed. In one series of trials, children learned that the longest side of the teeter-totter would always fall ("relevant" condition). In another series of trials, they learned that the side supporting a red block would always fall (the "irrelevant" condition). Ausubel and Schiff found that kindergarteners required the same number of trials to learn either relationship, while sixth graders required significantly more trials to learn the irrelevant relationship than the relevant relationship. The authors suggested that the older children's greater experience with teeter-totters might have facilitated their learning the relevant relationship, as well as inhibited their learning the irrelevant relationship.

In general, investigators looking at the use of stimulus information have argued that the preschooler's appreciation of cause-effect relations is incomplete relative to older children's or adults'. Preschoolers rely more on temporal contiguity, even when additional information such as regularity or covariation is available. The differences between older and younger children are not, though, usually ascribed to reasoning or inference processes per se, but to other processes such as memory (Shultz & Mendelson, 1975), perceptual distractibility (Siegler, 1975), differential weighting (Wilde & Coker, 1978), or familiarity with the events (Berzonsky, 1971; Ausubel & Schiff, 1954).

While studies in the empiricist tradition provide a good deal of valuable information concerning the cues children can and do use, they do not, in our opinion, provide a complete account of children's causal understanding. Attributions in these studies were undoubtedly influenced by the stimulus information. However, the very fact that children used some, but not all, of the available stimulus information suggests that some organization guided the use of stimulus cues. In other words, children's attributions may have been directed by hypotheses about ways in which events could be causally related. This suggests that a characterization of causal reasoning that stresses the *interpretation* of physical situations, rather than the use of kinds of stimulus information, might provide a richer, more satisfactory account of children's understanding.

In offering this criticism of the empiricist approach, we do not mean to deny the role of stimulus cues in children's causal reasoning, but only to suggest that

the interpretation of such cues may be constrained by children's assumptions about the nature of cause-effect relations. We would further argue that studies focusing on stimulus information may be tacitly testing principle use. Those children who pay attention to order cues may do so because of a principle of priority; similarly, those whose responses vary with spatial contiguity cues may be following a principle of mechanism that directs them to look for possible contact. Differences between younger and older children's attributions might then be interpreted to reflect younger children's inabilities to formulate satisfactory hypotheses concerning the way in which specific causes might be connected to their effects, due either to their limited physical knowledge or to their failure to use underlying adult causal principles. This final suggestion leads us to the structuralist approaches to causal understanding.

STRUCTURALIST STUDIES

A second line of research has focused less on children's use of particular stimulus information, and more on the issue of principle development. In contrast to characterizing developmental differences in terms of changes in the ability to extract causal relations from stimulus arrays, this view asks about children's criteria for defining events as causal.

Such a focus underlies the work by Piaget (1930, 1974), who claims that children's use of stimulus information is different from adults' because they interpret it according to different criteria or principles. He and his collaborators asked children to explain a variety of natural phenomena (e.g., the cycle of the moon, the floating of boats) and mechanical events (e.g., bicycles and steam engines). Analyses of the children's explanations led Piaget to characterize the preschool child's thought as *precausal*. Young children appeared to be fundamentally indifferent to causal mechanisms. Unlike older children, they never concerned themselves with the question of *how* a cause could actually bring about an effect, but took co-occurrence in time or space as sufficient indication of a causal relation. Young children also appeared indifferent to the temporal direction in which causal events occurred, taking the first or the second of two successive events as cause of the other. Finally, children did not restrict the types of events that could be causally related, attributing nonphysical causes to physical events. This is because the preschooler's approach to reality is profoundly subjective: the physical and psychological realms of their everyday experiences are not yet fully differentiated, and children do not distinguish physical, psychological, and supernatural events as being of different types. Thus, children often attributed the results of their actions to their own wishes and feelings, or explained the displacements and transformations of inanimate objects in terms of properties and motivations more appropriately reserved to sentient beings.

PP1 (30).max

According to Piaget, then, the structure of the young child's thought is qualitatively different from that of an older child or adult. While there is empirical support for Piaget's observations (e.g., Dennis & Russell, 1940; Laurendau & Pinard, 1962), his conclusions may be questioned on both theoretical and methodological grounds.

First, the standard Piaget used in evaluating his subjects's explanations may have been too stringent. Only those children who offered correct explanations were classed as demonstrating "truly causal" understanding. It is not clear, though, that adults would always be granted "truly causal" understanding given these criteria. It is not uncommon to hear mention of psychological causes ("*My car died*"), omission of mechanism ("*The moon affects my mood*"), or causation by an aspect of the event ("*The cup broke because it's fragile*"). It is unlikely that adults who give these sorts of explanations lack principles of causation such as mechanism, although it is difficult to tell from their explanations. Moreover, without precise knowledge of elementary physics, explanations will be less precise and, according to the Piagetian position, less advanced developmentally.

Investigators have also questioned Piaget's conclusions because of the nature of the phenomena Piaget asked his subjects to explain. Most of his questions concerned events with which young children have little direct contact (e.g., the moon, steam engines). Yet, many investigators have noted that the quality of children's explanations is directly related to their familiarity with the target events (e.g., Berzonsky, 1971; Huang, 1943; Mogar, 1960; Nass, 1956). Finally, Piaget's conclusions that preschoolers' thoughts are precausal are based almost exclusively on explanation data. Harkening back to our earlier discussion of kinds of knowledge, the ability to provide an explanation for an event may require far more than an understanding of how the event is produced. Whichever criterion one uses to classify children's explanations, there always remains the distinct possibility that children's poor explanations reflect their limited verbal skills, and/or an inadequate understanding of what constitutes a good or satisfactory explanation.

All of this suggests that Piaget's account of the development of causal reasoning may be inaccurate: his criteria for mature causal reasoning may be too stringent and, given the added requirement of articulated explanations, may assess more than causal thinking.[5] Nonetheless, the Piagetian position is important because of the focus on the underlying organization of causal understanding.

[5]Of course, Piaget's treatment of causality in the infant derived from behavioral, not explanation, data. However, in the Piagetian account, causal reasoning depends on representational abilities denied to the infant, so the issues of underlying definitional principles would not be relevant during the sensorimotor period.

Let us assume for a moment that when children reason about causes and effects, they do *not* abide by the same principles as adults. How then do they later come to recognize and use these principles? Piaget argued that the young child starts off with incorrect beliefs and, over development, comes to construct the correct adultlike beliefs. Alternatively, it could be that the young child makes *no* specific assumptions about the nature or status of cause-effect realtions, and adopts the adult's beliefs one by one, at successive points in development. (Koslowski, 1976, makes this argument with respect to the belief in mechanism.) In any event, whether one believes children proceed from an absence of beliefs or change erroneous ones, they are postulated to reason about causal events in a mode qualitatively distinct from adults.

Alternatively, adults and children might share the same reasoning principles and thus have the same implicit causal theory. This does not deny that young children perform less well than older children in causal tasks, but it interprets those failures differently. Huang (1943), for instance, collected explanations for various phenomena from children aged 5–10 years and college students. He concluded that children's and adults' explanations differed only in sophistication and particular content, not in form, and suggested that specific knowledge plays a large role in causal explanations. Perhaps it is not the principles that change with development, but rather the ability to apply these principles to a broad range of events, and to access them to mediate the content of explanations.

The conceptual differences between this alternative and the preceding one lie in the question of whether or not there is a qualitative shift in the structure of causal reasoning over development, and in the role granted to specific experience. Thus, when attempting to distinguish betweeen these two alternatives, the empirical task becomes one of asking *whether* preschoolers' causal judgments seem constrained (as are adults') by particular underlying causal principles, and *how* the nature and extent of specific knowledge affects causal attributions.

If young children reason about events according to a tacit definition of cause-effect relations similar to the adult's, we should find that they assume events obey the principles of determinism, priority, and mechanism, they should use spatial and temporal information in particular ways, and relate object states across transformations. However, since the extent of any specific knowledge base changes ontogenetically, the content and sophistication of causal *explanations* should demonstrate the most obvious change—not only in form, but in accuracy as well.

The remainder of this chapter will discuss research work that led us to favor the alternative that children and adults share the same causal reasoning principles. In our empirical work we have focused on tacit knowledge rather than explicit explanations, and we have considered reasoning about a limited class of events: those that involved inanimate objects (e.g., physical events), were discrete, temporally bounded sequences, and that afforded clearly separable cause-effect components.

PP1 (30).max

In exploring the structure of children's thinking about physical causality, we addressed two related developmental questions: (*a*) Do preschoolers show evidence of reasoning about causal matters according to the same principles as adults? (*b*) What role *does* factual information play in children's causal attributions, and how is this reflected in their judgments and explanations of events?

EMPIRICAL STUDIES

We have attempted to test the issues raised in the last section by examining causal understanding in preschool-aged children. There are, of course, substantial methodological problems in studying thinking in very young subjects. For one thing, it is not always easy to decide whether a child's inferior performance on a particular task should be ascribed to poor verbal skills, task difficulty, motivational deficits, or truly deficient reasoning. Until the first three factors have been ruled out, one cannot draw definite conclusions about the status of the child's understanding.

In our research we have attempted to rely less on explanations than on other responses, such as predictions, judgments, and direct manipulations. We, like others (e.g., Brainerd, 1977; Donaldson, 1978), take the position that the underlying structure of a child's knowledge may not be reflected in that child's verbalizations. Those investigators who have characterized preschoolers as "precausal," most notably Piaget, have done so primarily on the basis of explanation data. In general, children's explanations *are* different from older children's and adults'. When asked to talk about events, children do seem to violate the principles of determinism, priority, and mechanism. Since it is not clear how to interpret these data, we structured our tasks so that children's predictions and judgments could serve as the primary data base.

Task difficulty and motivational variables were also taken into account. In some studies children were shown novel, although very simple, event sequences; in others we used relatively complex event sequences, but allowed children to become familiar with them before being tested. Serious efforts were made to construct events that would be attractive to young children and that could actively involve the subject in the procedures.

In general, our tasks involved presenting children with event sequences that could be interpreted in different ways, depending on the presence or absence of a set of underlying principles defining cause and effect. By careful analysis of judgments, predictions, and attributions, we hoped to infer the reasoning that guided children's responses. For example, if the choice of an event as cause

carries with it the belief that there must be some connection between cause and effect (the mechanism principle), sequences in which antecedent and end components have no obvious means of contact should elicit different reactions than sequences in which a plausible connection is available. Similarly, if temporal order determines causal direction, then only antecedent events should be chosen as causes.

The studies reported in the following sections provide converging evidence on preschoolers' causal reasoning abilities. In some cases, we compare responses within one study; in others, we compare responses across experiments. This method is not direct: There are considerable inferential leaps from a description of what children do and say in different tasks to a description of their causal understanding. Still, in the course of this chapter we hope the reader will come to agree that these leaps are warranted, and that it is indeed possible to tap young children's knowledge about causal relations in the physical world.

The order in which the studies are reported traces the different questions we have raised concerning causal understanding: (*a*) Do children's attributions reflect underlying principles that define cause-effect relations? (*b*) How is stimulus information used in causal judgments? (*c*) How does knowledge of specific events or general transformations influence causal judgments?

Causal Principles

To find out if in fact children's reasoning is based on tacit causal principles, we designed studies that made it possible for children to behave in one way if their judgments were mediated by a principle, and to behave in another way if they were not. In this manner, we could see if situations informed by a principle made a difference.

PRIORITY

Bullock and Gelman (1979) investigated 3-, 4-, and 5-year-olds' use of the priority principle to identify the cause of an event. Subjects were shown a sequence of three events (X-Y-X'), and were asked whether the first (X) or the last (X') event was responsible for the occurrence of the intermediate event (Y). The first and last events were physically identical: each consisted of a ball rolling down a runway. The intermediate event was a jack-in-the-box popping up. The apparatus, pictured in the top half of Figure 8.1, consisted of two mirror-image ball-runway boxes, placed on either side of a jack-in-the-box. The ball events were produced by dropping a ball in a hole in the top of each runway box; the

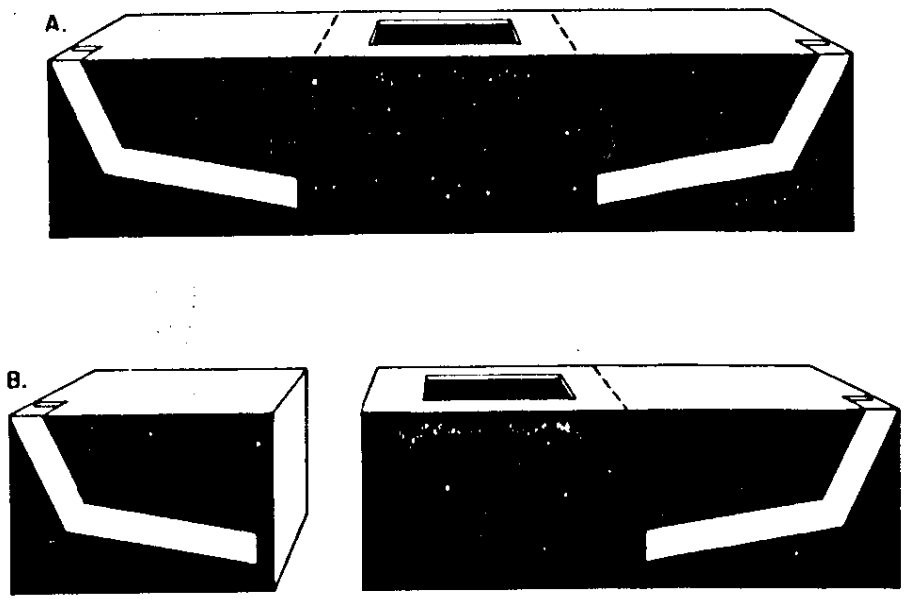

Figure 8.1. Apparatus for priority study. A. Configuration for initial demonstrations. B. Configuration for "separated" control conditions. Reprinted with permission from *Child Development*, 1979, *50*, 89-96.

runways gave the appearance of disappearing into the jack box. Children saw three demonstration sequences (the location of X or X', that is, to the right or left of the jack, was counterbalanced across subjects). They were asked which ball had made the jack come up. Bullock and Gelman reasoned that children who were truly indifferent to the order of cause and effect would choose at random between the first and last events; by contrast, children who assumed that causes can only precede their effects in time would consistently select the first, antecedent event as cause. They found that 75%, 87%, and 100%, respectively, of the 48 3-, 4-, and 5-year-olds tested consistently chose the first event as the cause of the jack popping up.

This result suggested that children as young as 3 years of age shared the adult's assumption of priority. To assure that it was order per se that directed the subjects' choices, Bullock and Gelman included two control manipulations at the end of their procedure. The two manipulations were always introduced in the same order. The first one controlled for differential attention to the X over X' event by presenting both components separately with the jack. When then shown the initial X-Y-X' sequence again, a choice of X over X'—coming after direct

PP1 (30).max

experience with each component—would provide stronger evidence of the use of the priority principle.

The second control manipulation pitted the priority principle against a cue of spatial contiguity. Lesser (1977) and others (e.g., Kosłowski & Snipper, 1977) have suggested that children are generally reluctant to choose an unconnected event over a spatially contiguous one as the cause of an effect. A violation of spatial contact, but not priority, would thus present children with a potential conflict. Faced with such a situation, adults rank temporal order above spatial contiguity and pick the first event because the assumption of priority precludes a cause ever following its effect in time.

At the start of the second manipulation, the *X*-runway box was moved 2 in away from the jack-in-the-box, resulting in the configuration shown in the bottom half of Figure 8.1. Children were shown two kinds of sequences: *X*(separated)-*Y*-*X'* and *X'*-*Y*-*X*(separated). The children again were asked which event was responsible for the jack's coming up. A choice of *X* in the first case, but not the second, would indicate that the children relied on the principle of priority, even when it conflicted with the spatial cue. Such a choice would go a long way towards indicating that children not only shared adults' assumption of priority, but recognized the inviolable character of this principle, and interpreted temporal and spatial information accordingly.

Table 8.1 summarizes children's choices across all experimental conditions. Regardless of the location (left or right) of the first event or the spatial gap, children consistently selected the prior event as the cause.

TABLE 8.1
Percentage of Children Who Chose on the Basis of Temporal Order During Experimental Trials in Priority Study (Bullock and Gelman)[a]

Type of demonstration trial	Age		
	3 years	4 years	5 years
1. Initial demonstration	75	87.5	100
2. Judgment after seeing that both *X* and *X'* could be causes	87.5	100	100
3. Judgment when first event is separated (*X*-*Y*-*X'*)	87.5	100	87.5
4. Judgment when previously second event is first (*X'*-*Y*-*X*)[b]	75	93.8	100

[a] Adapted, with permission, from *Child Development*, 1979, *50*, 89-96.
[b] An order-based choice is to pick *X'* in this condition.

Bullock and Gelman also analyzed children's explanations of their judgments. They found that only the older children verbalized the basis of their choice: 63% of the 5-year-olds and 43% of the 4-year-olds mentioned temporal order. In contrast, most of the younger subjects either gave no explanation or mentioned (without giving any justification for doing so) some portion or other of the sequence (e.g., "*Ball went*"). Still, the 3-year-olds consistently selected the temporally prior event as cause, strongly suggesting that they believed that causes must precede their effects. That they were unable to articulate the principle that guided their choices (i.e., priority) in no way precludes the possibility of such a principle being available and operative. Rather, it suggests that children's abilities to use a particular principle may long precede their articulation of that use. The existence of such a delay is not surprising given what we know of the development of metaconceptual abilities (e.g., Flavell, 1979).

MECHANISM

Two studies addressed the principle of mechanism. One, the Jack-in-the-box study, compared children's attributions and explanations when a plausible connection between cause and effect was or was not available. The second, the Fred-the-rabbit study, collected children's descriptions of a chain of cause-effect events and their predictions of what would happen when the sequence was modified.

The Jack-in-the-Box Study

Bullock (1979) conducted two experiments that provide information about preschoolers' tendencies to consider the need for a mechanism linking cause and effect events. She utilized variations in a simple event sequence.

Imagine the following: You see a long box. Across its opaque face are two parallel, horizontal windows, sloping downward and covering the left ⅔ of the box. While you watch this box you see two things occur simultaneously: a ball rolls across one of the windows and a light "rolls" across the other window. Both ball and light pass out of sight simultaneously, and a second or two later a jack-in-the-box jumps up from the area of the box to the right of the runways. On the basis of temporal and spatial information, both events are potential causes for the jack's jumping. However, most adults and 3- to 5-year-old subjects in a pilot test (Bullock, 1976) reported that the ball was the cause; it made the jack jump by hitting or releasing it. Subjects focused on the ball rather than light in their attributions, presumably because rolling and hitting can produce movement in another object through impact, while illumination cannot. Thus it seemed that

PP1 (30).max

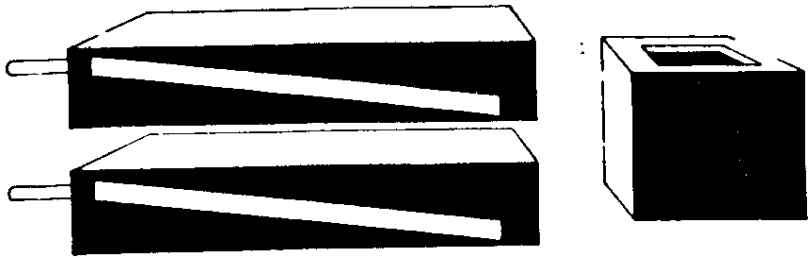

Figure 8.2. Components of the Jack-in-the-Box apparatus.

event type and possible mechanism were matched. However, subjects may have chosen the ball rather than light because they classed illumination as effect, not cause, or because the ball and jack made noise while the lights did not. To analyze *what* information subjects used and whether choosing the ball reflected an underlying principle of mechanism, Bullock repeated this procedure as a *standard sequence* and compared responses with another *unconnected sequence* in which the stimulus cues did not provide a choice consistent with a principled assumption of mechanism. The apparatus for these studies is illustrated in Figure 8.2. It consisted of three component boxes, each made of wood with a shiny black front (see Bullock, 1979, for a complete description). One of the boxes contained a jack-in-the-box (more precisely, a Snoopy-in-the-box) that was operated by a remote control, silent radio transmitter. The other two component boxes had clear windows across their faces. Behind one window was an inclined runway down which a ball could roll and fall silently out at the rear of the boxes. A series of small lights was mounted behind the other window; when the lights were flashed in succession they created the impression of a traveling light.[6] Each box additionally had a colored handle mounted on the side next to the window. The handles could be deflected by pushing down on them; they returned automatically to a horizontal position. The ball and light boxes were stacked one on top of the other (the order varied), and were the same height as the jack-in-the-box.

Although the apparatus consisted of component pieces, each of which was operated independently, it could be assembled so that it appeared to be one box. If the ball or light movement was begun as a handle was deflected, it looked as though the handle had released the action; when the ball and lights preceded the jack, it looked as though they, not a hidden switch, produced the jack's jumping. The events were carefully timed to support the impression of a unified sequence.

[6]This is the *phi phenomenon*. Since it is not clear that the children in Bullock's studies actually saw the lights as one traveling light rather than a series of sequential lights, we refer to it as a traveling series of lights.

PP1 (30).max

The ball and light events took 2 sec, there was a 1-sec lag, then the jack popped up.

In the comparison or *unconnected* experiment, there was a 6-in gap between the end of the runways and the beginning of the jack so that now the ball and light seemingly disappeared just before the open space between the unconnected pieces of the apparatus. Again, after a pause, the jack popped up.

When adults watched the *standard* demonstration, they selected the rolling ball as the causal event. However, when they watched the *unconnected* demonstration, they either rejected both antecedent events as plausible causes or chose the light event. Such choices reflect a concern with mechanism. In the *standard* demonstration the rolling ball disappeared into a spatially contiguous box; hence, its action served as an intermediary (e.g., hitting a lever or spring that released the jack). The light was an unlikely prop in such a mechanical device; hence, despite the fact that it shared the same temporal and spatial characteristics, namely, the outcome event, it was not as plausible a cause as the rolling ball. In the *unconnected* experiment, there was no spatial contiguity between the antecedent and outcome events. Thus, the ball could not in any visible way make contact with the jack-in-the-box. Indeed, neither could the light. However, adults do have considerable experience with electrical phenomena, which often appear to act at a distance and without any obvious spatial contiguity (e.g., light switches and ceiling fixtures; garage door openers, etc.). Thus, the adult who takes mechanisms into account might choose the light. He or she would be unlikely to pick the ball. Bullock reasoned that similar differences in preschoolers' causal attributions to the *standard* and *unconnected* demonstrations would reveal a sensitivity to mechanisms as well as concerns about the plausibility of one mechanism over another.

Sixty 3-, 4-, and 5-year-olds participated in the *standard* and *unconnected* experiments. Independent groups of 10 children from each age level served as subjects. Bullock used hand puppets to tell the children about the events they were to see, and to ask probe questions.

In both experiments, children saw the *standard* or *unconnected* demonstrations after they had become familiar with the runway portion of the apparatus. When a child entered the experimental room, he or she saw only the ball and light boxes, stacked one on top of the other (the box on the top or bottom was counterbalanced across subjects). The child was asked to push one of the two runway handles to "see what happens," and then to push the other. Children were asked to describe each of the runway events to be sure they could label the ball and light movements. The child was then told to "*Make the ball go*" or "*Make the light go*" at least three times. This phase ended with the puppet's asking the child whether he or she liked to see the ball or lights better. (There was no significant

bias across children, although 3-year-olds showed a slight preference for the light event.)

Phase 2 of both experiments began when the puppet told the child there was another part to the game and the child's job was to carefully watch everything that happened. The puppet then disappeared "for a nap" and the experimenter brought out the jack-box and either joined it (*standard* experiment) or placed it 6 in away from the ball and light boxes (*unconnected* experiment). Children in both experiments watched three identical demonstration trials: the ball and light began together in time, took 2 sec to travel down their respective runways, disappeared, there was a 1-sec lag, then the jack popped up. During these demonstration trials the handles were not used, although they were in place. To begin each trial the experimenter began the ball action from the rear of the apparatus, out of view of the child; the light event was yoked to the ball's action through an electrical circuit completed through the ball runway. The sequence was completed when the experimenter stepped on the hidden remote control for the jack-in-the-box, allowing it to spring up. After the demonstration trials, the puppet reappeared while the jack was visible and asked the child what had happened. Since all the children provided at least the information that the jack had come up (e.g., "Snoppy came," "it popped," etc.), children were asked how this had occurred, that is, for a causal attribution. Additionally, children were asked to explain *how* the ball, lights, or other stated cause made the jack come up. Following their verbal judgments and explanations, the jack-box was closed and children were asked if there was something they could do to make the jack come up again. Most children spontaneously pulled a handle; if they did not, the experimenter suggested it. The child's handle choice was noted.

By and large children in the standard experiment responded as adults did and picked the ball as the cause of the jack's action both in their verbal judgments and actions. Since handle choices and verbal choices were highly similar, we report only the judgment data. Table 8.2A lists the choices of the 30 3- to 5-year-olds in the standard experiment. From these data we can see that children (*a*) pick an antecedent as the cause of a particular event and (*b*) distinguish between the two types of antecedents.[7]

Bullock coded the childrens' explanations of their choices into three major categories on the basis of scoring systems used in the literature (e.g., Berzonsky, 1971; Laurendau & Pinard, 1962). The categories were *nonnaturalistic* (including no answers, animistic, or magical explanations), *phenomenistic* (merely restated the events seen without connecting them causally), and *mechanistic* (described the events and stated, or inferred, a causal connection). While there

[7]Only three children's verbal choices fell into the "other" category: They said that "wires" or "buttons" had made the jack pop up.

TABLE 8.2
Percentage of Children Making each Causal Choice for the Jack-in-the-Box Mechanism Experiments (Bullock)

A. Standard experiment

	Age		
Choice	3 years	4 years	5 years
Ball	70	90	70
Light	20	10	10
Other	10	0	20

B. Unconnected experiment

	Age		
Choice	3 years	4 years	5 years
Ball	70	10	40
Light	20	60	60
Other	10	30	0

were no age differences in children's choices, the explanations were a different matter. Only the older children's explanations fell into the most advanced category: 90% of the 5-year-olds, 50% of the 4-year-olds, and 10% of the 3-year-olds gave mechanistic explanations. The remaining children tended to give phenomenistic explanations, merely describing the events seen. Interestingly, Bullock found few nonnaturalistic or animistic explanations (two 3-year-olds, one 4-year-old), a finding consistent with other investigations of children's explanations for simple or familiar events (cf. Berzonsky, 1971; Deutsche, 1943; Huang, 1943).

The judgment choices of the 30 children who participated in the unconnected experiment are shown in Table 8.2B. While 3-year-olds tended to pick the ball as cause (as did the children who saw the standard events), 4- and 5-year-olds did not. A comparison of choices in this experiment with those in the standard experiment reveals that the two 3-year-old groups are indistinguishable, while older children responded differently ($\chi^2 = 9.7$, $p < .01$ for the 4-year-olds, and $\chi^2 = 4.2$, $p < .05$ for the 5-year-olds), with most 4-year-olds picking the light and 5-year-olds divided in their choices.

The explanation data suggest that the older children not only noticed the spatial gap, but used it in deciding which antecedent was the cause. Consider first the 5-year-olds: *all* who chose the ball as cause *also* postulated ways that this could have occurred. Their speculations included "very fast" balls, a pathway under

PP1 (30).max

the table, or invisible tubes: all implied mechanisms. Those 5-year-old children who picked the light tended to refer to some property of lights that would account for their causal impact, including "*the power of the lights*" or "*electricity can go over.*" The 4-year-olds, the majority of whom chose the lights, also mentioned connections, although they were less explicit about the mechanism. By contrast, the explanations of 3-year-olds made no mention of intermediary events or connections. Further, when directly asked whether the ball needed to make contact with the jack, only one 3-year-old agreed that it did.

As a check on her interpretation of children's responses, Bullock recoded each child's protocol for some expression of concern with the implications of the spatial gap. She counted expressions of surprise during the demonstration trials (e.g., "*How did* that *happen?*") or mention of a connection in either the choice or explanation trials. While 90% of the 5-year-olds and 70% of the 4-year-olds commented on the lack of spatial contact, only 20% of the 3-year-olds did so ($\chi^2_{(2)} = 10.83$, $p < .01$).

Since the 4- and 5-year-old children in both experiments behaved as adults did when confronted with the same demonstrations, it seems fair to conclude that these children did make inferences about mechanisms that can or cannot mediate cause-effect sequences. What can we make of the 3-year-olds' results? In the unconnected experiment, 3-year-olds revealed a remarkable indifference to matters of mechanism; they apparently believed that metal balls can act at a distance. One could conclude that 3-year-olds' understandings do not reflect a use of the principle of mechanism. Alternatively, one could argue that the children knew even less about electrical events than they did about rolling balls and hence had a limited knowledge base from which to make an informed decision. Experiments by Baillargeon and Gelman lead us to prefer the latter interpretation.

Fred-the-Rabbit Experiments

The preceding study suggested that some children's lack of concern about mechanism arose because they lacked specific knowledge about events, not because they lacked principles by which to reason. One way to test this question is to provide children with information about a causal mechanism and see whether they use this information to judge or explain events.

Baillargeon and Gelman (1980) conducted an experiment in which they varied what information 4- and 5-year-olds had about the intermediary parts of a sequence of events. They asked whether those children who knew the precise nature of the intermediary steps would use this information to explain the outcome of the sequence, and to predict how modifications of the sequence affected the outcome. If they did, it would suggest that children's alleged indifference to causal mechanism resides in their ignorance of what a particular mechanism might be, rather than a belief that mechanisms are irrelevant.

PP1 (30).max

Children were asked to describe the workings of the three-step sequence illustrated in Figure 8.3. The sequence included an *initial event* (an orange rod was pushed through a post), a *final event* (Fred-the-rabbit fell into his bed), and a series of *intermediary events* (the rod knocked down the first of five standing wooden blocks; each block fell upon the next in a dominolike fashion; the fifth block fell on a small lever which pushed the rabbit off a platform).

Sixty-four 4- and 5-year-olds participated in the study. Sixteen children of each age were randomly assigned to one of two conditions that varied the amount of information they had about the apparatus. Children in the *complete information* condition saw the entire apparatus during pretest demonstration trials. The experimenter pointed to each part, labeled it, and invited children to demonstrate the sequence. After the demonstration trials, a screen was put up that blocked from view the middle portion (blocks and lever) of the apparatus. All that the children could see was the rod and post to the left and Fred standing on the platform to the right.

Children in the *partial information* condition were never shown the middle portion of the apparatus; the screen was already in place when they walked into the experimental room. During pretest trials, the experimenter demonstrated the sequence by pushing the rod through the post. Since the screen was in place the children could see only the initial and final events; however, they could hear the blocks as they fell.

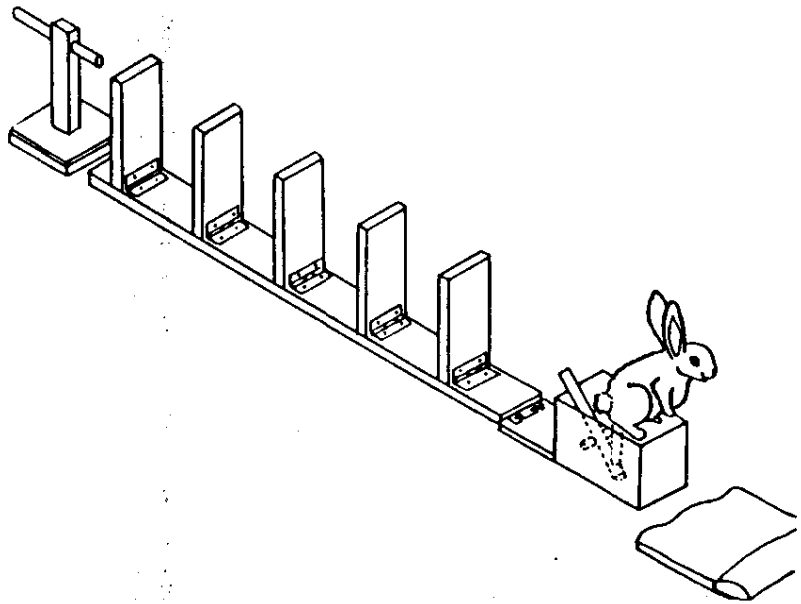

Figure 8.3. The Fred-the-rabbit apparatus.

After the pretest trials, children in both conditions were treated identically. In a first phase, the experimenter asked children to predict whether the rabbit would fall when she pushed the long orange rod through the post, and then to describe what had happened when the rabbit did fall. Not surprisingly, all children in the *complete information* condition correctly predicted that the rabbit would fall, and all but three were able to provide "integrated" descriptions of the event after the rabbit had fallen. A description was judged to be integrated if (*a*) all the component events comprising the sequence were mentioned; and (*b*) each event was indicated to be the effect of the event that preceded it and the cause of the one that followed it. Children in the *partial information* condition also correctly predicted that the rabbit would fall, although, of course, fewer of their descriptions of the sequence were rated as integrated. Still, 69% of the 16 5-year-olds correctly included the information that something must have connected the rod's action to the rabbit's. In contrast, the majority of the 4-year-olds answered that the rod had somehow pushed the rabbit off his box—an unlikely story since the rabbit stood more than 3 ft away from the post! Moreover, the children could hear the falling blocks.

In Phase 2, the experimenter introduced two modifications of the initial event, in random order. One modification was to substitute another orange rod that was too short to reach the first block when pushed through the post. The other modification involved substituting a long multicolored rod for the orange one. The first modification was labeled *relevant* since it should affect the outcome of the sequence (Fred should not fall); the second change was labeled *irrelevant* since it should not change the usual outcome (Fred should still fall into his bed).

Children were asked to predict whether Fred would or would not fall for each modification. Following each prediction, the experimenter demonstrated the sequence. Regardless of the modification type, though, the rabbit did not fall after either modification (the experimenter surreptitiously prevented the multicolored rod from hitting the first block). In both cases, children were asked to explain why the rabbit had not fallen. Two questions were of interest: Would children predict differently following relevant and irrelevant changes? Secondly, would explanations for the rabbit's failure to fall depend on children's prior information concerning the apparatus?

The results from the Phase 2 modification trials indicated that while children's predictions did *not* differ by information condition (half the children predicted Fred would not fall with the short rod; only one child predicted he would fall with the multicolored rod), their explanations for why the rabbit had not, in fact, fallen did differ.

All but two children in the *complete information* condition offered the correct explanation for why Fred failed to fall with the short rod. This is especially interesting when one considers that about half the children in this condition were incorrect in their predictions. After the rabbit failed to fall, these children revised their earlier judgments and correctly pinpointed rod length as the reason for the rabbit's not falling.

In contrast, when Fred did not fall following the irrelevant modification, children attributed the outcome to something other than the substituted rod. Twenty-one of the 32 *complete information* children said the experimenter had done something (e.g., moved the post away, put the blocks down, taken some blocks away) to prevent the rabbit's falling. An additional 8 children claimed the multicolored rod had somehow not pushed the blocks down.

These results suggest that children can and do use their knowledge of intermediary events in a causal sequence to reason about the sequence. Children in the *complete information* condition attributed an outcome to a modification *only* when their understanding of the sequence led them to infer that this modification effectively prevented the intermediary events from occurring. When the modification was *not* relevant to the sequence of events, children resisted attributing the outcome to it. It is notable that while children in the *partial information* condition performed less well, most of those children who *did* postulate some mechanism during the first phase also referred to hypothesized intermediary events in their explanations of the outcomes of the two modifications. This suggests that children's explanations are limited by their knowledge about *what* could connect cause and effect, not by a fundamental belief that such a connection is unnecessary.

Given that 4- and 5-year-olds could, if informed, explain modifications in a way that implied an understanding of mechanism, Baillargeon, Gelman, and Meck (1981) conducted a follow-up study that included even younger children. Twenty 3- and 4-year-olds were asked to predict the effects of a series of modifications to the rabbit apparatus after they had seen the complete event sequence in pretest trials. The children in this study were not asked to explain or describe the events, but merely to predict whether or not modifications would disrupt the expected sequence.

As in the earlier study, Baillargeon *et al.* included two types of modification: *relevant* modifications, which would disrupt the sequence; and *irrelevant* ones which would not. Modifications involved either the initial event (rod or post) or the intermediary events (blocks or platform). Children were asked to make 23 predictions. If they were truly indifferent to mechanism, they should not predict differently depending on whether the modification was relevant or irrelevant. Alternatively, predicting that the rabbit *would* fall after irrelevant changes, and *would not* fall after relevant changes would be evidence that children took mechanism information into account when reasoning about events.

The relevant changes to the initial part of the sequence included using a rod of soft, flexible material, a rod with a stopper that prevented it from going through the post and contacting the first block, a rod too short to hit the first block, or moving the supporting post so the rod could not contact the blocks. Relevant

PP1 (30).max

TABLE 8.3
Mean Percentage of Correct Predictions Following Modifications to an Event Sequence (Baillargeon, Gelman & Meck)

Modification type	Age	Source of modification: Initial event	Source of modification: Intermediary event
Relevant	3 years	81	78
	4 years	87	85
Irrelevant	3 years	88	96
	4 years	100	100

changes to the intermediary part of the sequence included putting the blocks down or moving the platform to one side of the blocks so the last block could not hit the lever. Irrelevant changes of the initial component included changing the color of the rod or the substance of the rod (from wood to glass), or moving the post position without affecting its function. Irrelevant changes of the intermediary components included putting a cloth around one block or putting a screen in front of the blocks.

Children were first asked about modifications to the initial event, then about those concerning the middle events. Within these categories, the presentation of particular modifications was random. For all changes children were asked to predict whether or not the rabbit would fall. Feedback was not provided.

Children's performance over the 23 predictions is shown in Table 8.3. The range of correct predictions was 78-91% and 70-100% for the 3- and 4-year-olds, respectively. Children's accuracy did not depend on whether the change was to the initial or intermediate part of the apparatus. Although there was a slight bias toward more accurate predictions for irrelevant changes, (i.e., children were more likely to accurately predict that a modification would not disrupt the sequence), all predictions were significantly above chance level (binomial test, all p values $< .005$).

Baillargeon *et al.*'s prediction data demonstrate that children as young as 3 years can use information about connecting mechanisms to reason about event sequences. The 3-year-olds' superior performances in this experiment, compared with the 3-year-olds in Bullock's *unconnected* experiment (see "The Jack-in-the-Box Study"), are likely due to the availability of specific information in Baillargeon *et al.*'s study. It seems that knowledge of actual mechanisms influences the child's willingness to refer to intermediary events in explaining occurrences. Thus, even 3-year-olds are sensitive to questions of mechanism in some situations.

PP1 (30).max

DETERMINISM—A CONTROL CONDITION

To assess the assumption of determinism essentially requires asking if there exist any conditions under which a child believes that events may not be caused. While it would be impossible to investigate this question for all possible events, a belief in determinism may be demonstrated if a child resists attributing an event to "itself," or actively searches for a cause for a seemingly causeless event.

Bullock (1979) conducted a control study for the jack-in-the-box experiment to test the determinism assumption. Bullock provided a seemingly uncaused event, but questioned children about it in a way that would allow them to attribute the cause to some plausible, but inappropriate, event, or to say that the event needed no cause. The procedure for this study was identical to that described for the Jack-in-the-box study. In the first phase children became familiar with the runway portion of the jack-in-the-box apparatus and learned to push handles to make the ball and light events occur. The jack-in-the-box portion of the apparatus was attached to the runways, and children watched demonstration trials during a second phase. In the previously described jack-in-the-box study, ball and light action preceded the jack; children attributed the jack's jumping to these antecedents. In this study the runway events did *not* occur during the demonstration phase: the jack simply jumped up. After watching demonstration trials, children were asked for a causal judgment, that is, how the jack had come up. If a child claimed ignorance or surprise, the experimenter probed him or her in a way to allow animistic ("*It wanted to*") or inappropriate (e.g., "*The ball* (or light) *did it*") causes. The experimenter asked the child if the jack had come up by itself, or if not, what had been the cause. Of interest in this study was whether children would resist the opportunity to say that the event occurred on its own or was the effect of the ball or light—the only other salient occurrences in the experimental setting.

Thirty 3-, 4-, and 5-year-olds participated in this study. When asked what made the jack pop up after the demonstration trials, only five children (three of these 3-year-olds) mentioned the ball or light. The other children either accused the experimenter of playing a trick, complained that there was no way of determining the cause, or claimed that something—though they knew not what—was the cause. Thus, children indicated that they believed some causal event was required.

Children's explanations were instructive. In contrast to subjects in the earlier jack-in-the-box mechanism experiment, children in this study neither referred to the ball and light events nor put the impetus for the causal action in the jack itself. Rather, most children tried to specify the nature of the cause that was responsible for the event they had witnessed. Consistent with the other studies reported thus far, the older children were better at this than the younger. While only 40% of the

3-year-olds speculated about what the cause could be, 70% and 90% of the 4- and 5-year-olds did. They said that wires, buttons, or switches were the cause, indicating not only a belief that there must be some cause, but also suggesting its identity.

Following completion of the explanation phase of this study, 20 of the 30 subjects saw one additional trial where the ball and light *did* occur. All children, when asked, now attributed the cause of the jack's action to one of the two antecedents; 65% of them additionally showed signs of relief or amusement.

In sum, responses to this condition offer support for at least a weak assumption of determinism: children claimed that what appeared to be an uncaused event required some explanation, even if they could not specify the details. This finding was consistent with earlier (Bullock & Gelman, 1979; Gelman, 1977) "magic studies" in which children reacted with surprise and amazement to surreptitious alterations in object arrays, and often searched for the cause of the change.

The Use of Stimulus Information

In outlining the model of causal thinking, we distinguished between the use of causal principles and the use of specific information from events to arrive at a causal attribution (see "A Characterization of Causal Reasoning"). In many of the studies reported here causes were spatially and temporally contiguous to their effects, providing a good deal of redundant information about the events. Hence, these studies do not allow us to ask about the relative contributions of stimulus information (especially temporal and spatial contiguity) to causal attributions in the particular case.

There are two exceptions to the generalization about redundant temporal and spatial information. First, children in Bullock's unconnected experiment were shown events that were temporally but not spatially contiguous. The 4- and 5-year-olds in that study paid attention to the spatial gap and selected causal events that might rectify the situation so that spatial and temporal contiguity cues applied (e.g., they suggested tubes under the table for the ball, or that an object really had made spatial contact, etc.). Three-year-olds, though, seemed perfectly content to select the steel ball as cause and did not mention the lack of spatial contact. This result suggests that the youngest children relied on temporal priority alone.

A second exception occurred at the end of the Bullock and Gelman study on priority (see "Causal Principles"). Here, temporal and spatial information was inconsistent so that the event that preceded an effect was not spatially contiguous to it, while an event that followed the effect was. Again, 4- and 5-year-olds were surprised at this and tended to invent mechanisms that would preserve both

PP1 (30).max

temporal and spatial contiguity; and, again the 3-year-olds seemed to base their judgments on temporal information only.

It is just this sort of lack of interest in spatial contact information that has led children to be characterized as "precausal." However, the Baillargeon et al. studies reported here suggest that 3-year-olds were not oblivious to mechanism information under some conditions. One alternative interpretation, then, is that under conditions of ignorance about *possible* or likely mechanisms, younger children's choices are guided more heavily by the priority assumption, suggesting they will *overlook* cues from the stimulus environment. Further, children may need to learn the relation between spatial cues and the mechanism principle; after all, there are many spatially unconnected events that are causally related (light switches and illumination, TV controls, commands and answers, and so on).

One way to assess the role of stimulus information in causal attributions, though, is to ask whether children, like adults, use *relative* contiguity to choose between two or more plausible causes, and whether temporal or spatial information is weighted more heavily. Bullock and Baillargeon (1981) focused on asking whether children's causal judgments would vary with relative temporal or spatial contiguity.

The apparatus for this study used the same components as the Bullock and Gelman (1979) study on priority (see Figure 8.1). That is, a ball event could occur in either of two boxes adjoining a jack-in-the-box. Here, though, both ball events occurred before the jack jumped under all conditions. What varied was the *relative* temporal or spatial contiguity relation of each of the ball events to the jack, that is, the timing of the balls or the placement of the ball boxes.

The design for this study included the four conditions outlined in Table 8.4. In all cases the possible causes *preceded* the effect. In Conditions 1 and 2, either temporal contiguity or spatial contiguity varied alone. In Conditions 3 and 4, both temporal and spatial proximity varied so that the cues were either consistent (one event was closer in time and in space) or inconsistent (one event was closer in time, one in space). By comparing children's choices within each condition, and across the four conditions, Bullock and Baillargeon assessed how particular information was weighted in determining a cause.

Seventy-two children (24 3-, 4-, and 5-year-olds) saw the four conditions. For half the subjects the spatially proximate box was connected to the jack, and the other box was 6 in away. For the other half of the subjects, the boxes were always separate, one at 2 in and one at 6 in. Children saw six trials for each condition; on each trial they were asked to judge which ball event had made the jack pop up. On two of the six trials children were asked to explain their choices. Conditions 1 and 2 were always presented first, in counterbalanced order. Trials for Conditions 3 and 4 were mixed and presented in random order.

Responses were coded separately for each of the four conditions. The pattern

TABLE 8.4
The Four Conditions Varying Stimulus Information (Bullock and Baillargeon)

Condition	Spatial configurations				Temporal sequences
1. Relative temporal contiguity (TC) Varies alone	1[a]	2	3		1-2-3 or 2-1-3
2. Relative spatial contiguity[b] (SC) Varies alone	1	3		2	1, 2 simultaneous, followed by 3
	or 1		3	2	
3. Consistent Temporal and spatial contiguity	1	3		2	2-1-3
	or 1		3	2	1-2-3
4. Inconsistent Temporal and spatial contiguity	1	3		2	1-2-3
	or 1		3	2	2-1-3

[a] The numbers refer to the components of the apparatus: "1" and "2" represent the runway boxes; "3" represents the jack-in-the-box.

[b] In conditions 2, 3, and 4, two configurations were used over the trials. In condition 2, the timing remained constant with the two configurations; in conditions 3 and 4, the timing changed to allow spatial and temporal cues to be consistent or inconsistent.

of choices for each set of six trials was classified as consistent with one cue if at least five of the choices used information determined by that cue, and as "indifferent" if not. For example, a child in Condition 2 would be classed as using the cue of spatial contiguity only if he or she chose the closer event on five or six of the trials. If he or she chose the closer event two, three, or four times, the choices would be classed as "indifferent." Choosing the more distant event five or six times would be classed as a negative use of the spatial cue.

Table 8.5 summarizes the pattern of choices for the three age groups and a subsequently tested group of adults. Since there were no differences between the three groups of children depending on whether they saw the connected or close configurations, this factor is collapsed for this presentation. The results for Condition 1, where relative temporal continguity varied alone, were surprising. Those theories that posit that the preschooler is "precausal," limited to or primarily reliant on temporal cues alone, would predict that children's choices in this situation would favor the event that was more contiguous temporally. This should have been the most straightforward of all conditions. However, children's choices indicated that, far from *relying* on temporal continguity, they did not even use it (except, of course, that both antecedents were near to the effect in time in an absolute sense). By and large children picked the first event in the sequence as cause, or were indifferent. The 5-year-olds were more consistent in their choices than were the younger children—a trend that was mirrored in the

other conditions. This finding led Bullock and Baillargeon to test an adult group as a check on their intuition that adults *would* pick a temporally more contiguous event as cause. The 12 adults, whose choices are indicated in Table 8.5, were more likely as a group to pick the more contiguous event, although there was not unanimous agreement. Those adults who picked the first event, though, also mentioned that they supposed some mechanism was slowly linking the first event to the effect, and there was not enough time for the second event to get to the jack. In contrast, the children picked the first event and said they picked it *because* it was first, a dubious justification, although one that is consistent with a use of the priority principle.

Conditions 2, 3, and 4 each involved spatial proximity information, either alone (Condition 2) or in combination with temporal cues (Conditions 3 and 4). For all subjects, of all ages, the configuration with the greatest relative *spatial* proximity between cause and effect was picked over the other configuration regardless of the temporal cue. While over half the 3- and 4-year-olds chose

TABLE 8.5
Percentage of Subjects Classified as Choosing by Stimulus Cue or as Indifferent (Bullock and Baillargeon)

Condition		Cue Classification		
1. TC varies alone		TC	First	Indifferent
	3 years	4	16	79
	4 years	4	42	54
	5 years	13	50	38
	Adults	58	33	8
2. SC varies alone		SC	−SC	Indifferent
	3 years	42	4	54
	4 years	63	0	38
	5 years	75	0	25
	Adults	100	0	0
3. TC/SC consistent		SC/TC	First	Indifferent
	3 years	17	4	79
	4 years	58	4	38
	5 years	63	13	25
	Adults	100	0	0
4. TC/SC inconsistent		TC	SC/First	Indifferent
	3 years	4	25	71
	4 years	0	46	54
	5 years	0	75	25
	Adults	25	58	17

PP1 (30).max

inconsistently enough to be labeled "indifferent" in their choices, those who did choose consistently opted for relative spatial proximity.

The age trends in this study deserve additional note. While younger children were primarily indifferent (or variable) in their choices, a common finding for young subjects, there is some indication that this was due to the complexity of the situation, not the absence of any criteria underlying their choices. First, 3-year-olds were *least* indifferent for the condition where spatial cues varied alone (Condition 2), suggesting mediation by a mechanism principle, as long as other information was held constant and only one cue varied. Secondly, the overall age trends showed that children became more consistent in their choices and more similar to adults' very consistent (with the exception of Condition 1) choices. It is interesting to note that children did not pick causes incompatible with the principles of priority or mechanism (the *inconsistent* antecedent in Condition 3 or the spatially removed box in Conditions 2, 3, or 4). This suggests that what changes with development is the knowledge of how to weight stimulus information in relation to the principles defining causal events.

The results from Condition 1, in which children picked the first event, suggests one area where adults' and children's criteria may differ in terms of weight given to contiguity information. It may be that children's definitions of causal events were such that they took the *first* salient occurrence as cause, and not the more contiguous one (either one is consistent with a priority principle). This question will be addressed in future studies that vary the temporal spacing between events even more, in an effort to see when children deny that the first event is the cause and pick a more contiguous one.

PP1 (30).max

Knowledge about Transformations and Objects

The ability to make causal inferences or to explain events relies in part on general knowledge about transformations and possible outcomes with respect to object states. This idea is a central component of those theories that describe the structure of representation, be it in terms of schemata (e.g., Piaget, 1974; Premack, 1976), scripts (e.g., Schank & Abelson, 1977), or schematic organization (Mandler, 1978). Our expectations about event outcomes—the way we parse occurrences—and our verbal explanations of events probably all make use of the notion that causation involves a transformation over time. In keeping with our earlier discussion, we may distinguish between the ability to comment upon the nature of transformations, and the use of this knowledge to trace changes in objects over time.

Consider, again, a rock shattering a window. When we understand this event, we may reason about it using temporal and spatial information to determine what is effect and what is cause. However, another way that we may reason about the

event is in terms of the transformation that changes the window from one state to another. The object of the transformation, the window, had a beginning and an end state (whole and broken) that were related in time by a transformation, breaking. Furthermore, the transformation was instantiated by an instrument, a rock.

The young child's understanding of the relationships that hold between components of an event, object states, and the transformations that link them, has not received much direct investigation. Yet, assumptions about just this sort of knowledge figure in theories of linguistic competence, conceptual organization, and causal and temporal reasoning. On the one hand, young children are granted tacit knowledge of the semantic categories that components of events fit into, for example, agent, object, location, and instrument (see Ammon & Slobin, 1979; Bowerman, 1978; Clark & Clark, 1977). Similarly, they are granted sensorimotor schemes for organizing objects and actions (Piaget, 1954). On the other hand, children of the same ages are characterized as unable to *reason* about the relation of causes and consequences and as unconcerned about the specific nature of a transformation that might connect two states of an object (Piaget, 1974).

The results presented in the preceding sections suggest that even very young preschoolers may reason about cause-effect relations according to the same basic principles as adults, even though they do not give all stimulus information the same weight or explain events with adultlike sophistication. A study by Gelman, Bullock, and Meck (1980) indicates that young preschoolers are also capable of relating object states through appropriate transformations.

Gelman *et al.* (1980) investigated children's understandings of transformations and object states by asking 3- and 4-year-olds to fill in missing elements in three-item picture stories. Each completed sequence consisted of an object, an instrument, and the same object in another state. Figure 8.4 illustrates some of the complete stories. Note that some sequences depicted everyday events, others "bizarre" events, such as sewing a cut banana together or drawing on fruit. The latter type of sequences were included to control the possibility that when children had to fill in a missing slot, they did it simply on the basis of everyday memories.

Following pretraining trials to teach a left-right "reading" of the sequences, children were shown test sequences with either the first, second, or third positions empty. The task was to pick one of three choice cards to fill in the missing slot, and to tell the story depicted by the three cards. Examples of trial sequences with each position blank and the three choice cards are shown in Figure 8.5. Test sequences included two broad categories of transformations. One type altered an object from a standard, or canonical, form, (e.g., wetting, breaking, cutting, and so on). A second type restored objects to a more canonical form (e.g., drying, fixing, erasing, and so on).

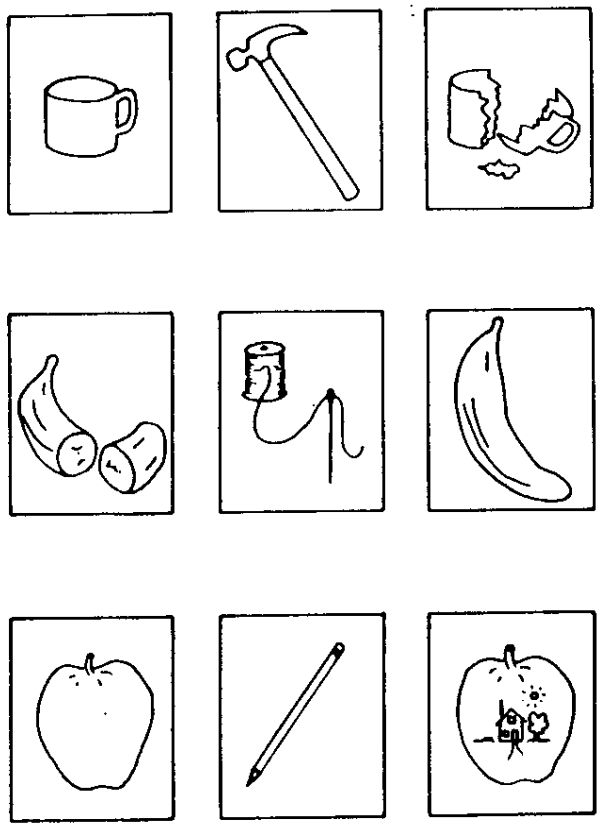

Figure 8.4. Three examples of story sequences. Reprinted with permission from *Child Development*, 1980, *51*, 691-699.

Gelman *et al.* used these story sequences to test children's understanding of causal transformations by asking whether children could reason from two of the elements in the story to the (missing) third. That is, could they infer the instrument that related two object states, predict the result of a transformation given an object and instrument, and retrieve the initial state of an object, given an instrument and final state?

Forty-eight 3- and 4-year-olds participated in the study. Half the children saw sequences that altered objects (the *canonical condition*) and half saw sequences in which an altered object was restored (the *noncanonical condition*).

Children did very well at filling in the missing items in the story sequences. Twenty-one of the 24 3-year-olds and all the 4-year-olds reliably chose the correct picture across the 12 trials, as illustrated in Table 8.6. There are several noteworthy trends in these data. First, the older children made few errors overall,

regardless of type of transformation or familiarity of sequence. When they did err, it tended to be in retrieving the initial state of the event sequence. While the 3-year-olds' responses also showed no difference depending on common or unusual sequences, they, unlike the older children, were influenced by whether the transformation altered or restored an object. The younger children who saw noncanonical (or restoring) transformations tended to make more errors, suggesting it was easier for them to reason about sequences in which an object is changed away from its standard state. Finally, all children found it relatively easier to fill in the instrument slots than the object slots.

The differences in error scores between canonical and noncanonical altera-

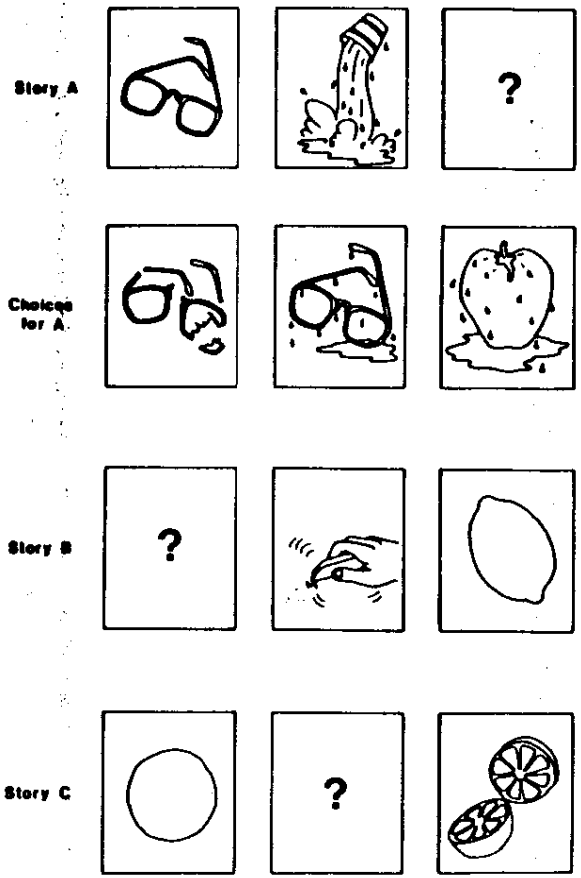

Figure 8.5 Examples of test sequences for the picture card studies. The correct answer for Story B is a lemon with a drawing on it; the correct answer for Story C is a knife. Reprinted with permission from *Child Development*, 1980, *51*, 691-699.

PP1 (30).max

TABLE 8.6
Percentage of Children Who Made at Least 75% Correct Choices on Each Story Position (Gelman, Bullock & Meck)[a]

A. Canonical stories

	Position of missing item		
Age	1	2	3
3 years	66	91.7	83.3
4 years	91.7	100	100

B. Noncanonical stories

	Position of missing item		
Age	1	2	3
3 years	58.3	75	58.3
4 years	100	100	100

[a] Modified with permission from *Child Development*, 1980, *51*, 691-699.

tions, shown only by 3-year-olds, were reflected in all children's verbal descriptions of their completed sequences. The content of children's descriptions were categorized for how "complete" they were. A *complete story* was one in which a child mentioned both object states and the transformation that related them, supplying the action implied by the picture sequence (e.g., "*There was that cup and the hammer broke it*"). *Less-complete stories* described just the action of the instrument ("*It broke it*") or listed the picture components ("*cup, hammer, cup*"). The older children told more complete stories than the younger ones did: on the average, 80% of the 4-year-olds' stories were complete; 41% of the 3-year-olds' were. However, stories of children in both age groups were more complete when they involved the canonical sequences than the noncanonical (44% versus 37% for the 3-year-olds; 89% versus 71% for the 4-year-olds). There were no differences in stories depending on position of the missing items.

In sum, although the youngest subjects made more errors, they still did very well. All children were able to predict or retrieve the missing object states and infer a transformation that linked object states through time. This is true for transformations that both were and were not likely to be a part of the children's everyday experiences.

Linking object states through transformations—an ability even 3-year-olds possess—is one aspect of the kind of general knowledge that would allow one to use causal principles to reason about and explain events. In one sense, though,

applying this knowledge implies a further ability: that one can think of cause and effect as *related*, through a transformation, in a coherent unit. This suggests that one not only has some schema, script, plan, or structure that frames the relation, but that one can also operate within those event representations. Thus, using one's knowledge is more than just relating events in time; it includes relating them in a larger context.

Piaget's theory of cognitive change emphasizes that the child only gradually develops structures that make it possible for him or her to escape the unidirectional nature of experience, and to think of transformations as related and reversible (e.g., addition and subtraction may be applied to any set of objects and may operate within a relational system). Preschool thought is characterized by Piaget (1974; 1976) as irreversible, implying that younger children are more constrained by the actual sequencing of events in time when they reason about those events. In the case of causal thinking, the preschooler is similarly presumed unable to consider together reversible or reciprocal transformations on objects. It is possible that this restriction is indeed a deficit in the child's reasoning; however, it is also possible that children's explanations and judgments about causal events most often are unidirectional in character because causal events *do* take place through time and are not, in reality, reversible (much to a preschooler's chagrin, broken dishes are irreparable, eaten cookies are gone, and dirty clothes stay dirty). A second study by Gelman *et al.* (1980) addressed this issue.

In the context of the preceding picture card study, the question of reversibility of causal thinking may be specified as follows. A child might be able to relate cause and effect in a specific instance, for example, seeing that hammering will produce a broken bowl or that gluing will fix it. However, he or she should have difficulty in thinking of the two actions, hammering and gluing, as a pair that reverse the effects of each other. To do this requires more than filling in implied actions or instruments; it involves separating the transformations on objects from their particular reference frame, and freeing them from temporally unidirectional occurrences.

To test whether preschoolers could treat transformations in such a general sense, Gelman *et al.* ran a second study, using a slight modification of the picture card procedure. Again, children were presented with the card sequences, but in each case the middle instrument card was the missing item. Children were asked to choose from four alternatives. As before, the choices included an appropriate instrument for reading the sequence from left to right. Additionally, there was an appropriate instrument card for reading the sequence in the reverse order, from right to left. On each trial, a child was asked first to choose an instrument that would complete a left-right reading of the story, then to pick a second instrument for a right-left reading. Thus, children were asked to think of the same object pair (e.g., blank and marked paper, broken and fixed cup, wet and dry dog) in two different ways.

PP1 (30).max

Forty-eight 3- and 4-year-olds participated in the second picture card study. Overall, children's first choices were not as accurate as those of children who participated in the first study. Three-year-olds were correct on 49% of the trials, and 4-year-olds on 75%. However, most errors consisted of picking a card appropriate for what was a "reversed" reading of the sequence, that is a right-left reading. If a child was allowed to respond in his or her preferred direction, 80% and 90% of the 3- and 4-year-olds' initial choices were correct, a figure consistent with the instrument choices for the first study. Fifty-eight percent of the 3-year-olds and 83% of the 4-year-olds then reliably picked a *second* accurate instrument card, demonstrating that they could interpret the object transformation in two reciprocal ways. Those 3-year-olds who did not do this included all the children younger than the median age of the 3-year-old group, suggesting that still younger children might have difficulty with reciprocal transformations.

The results from the second study suggest that while young preschoolers can represent events in a general enough manner to be able to abstract object states and transformations, this is neither easy nor automatic. The younger 3-year-olds were not able to "reverse," although they could infer what action linked object states in a single case. This suggests that the developmental changes in general reasoning abilities may be more profitably conceived as advances in the flexibility and generality of representation, rather than as changes in the form of representation.

PP1 (30).max

Explanations and Judgments

In all the studies reported, the procedures required explanations as well as judgments, predictions, or attributions. Across studies, two consistent findings recurred. First, children's explanations for events improved with age, even where there were no age differences in judgments or predictions, such as in the jack-in-the-box standard experiment or the priority experiment. Secondly, children's explanations for events did not seem to reflect the same level of causal reasoning as did their judgments or predictions. The evidence we interpreted as indicating reasoning by causal principles came from children's judgments or predictions; it did not come from their explanations. These results are, of course, not a surprise to anyone working with preschool-aged children. Children are more likely to demonstrate their reasoning in actions and simple choices than in explanations.

The question we wish to address in this section is what the differences between pictures of preschoolers' thinking gleaned from explanations and those from judgments might mean for the study and interpretation of the development of causal reasoning. On the one hand, we have implied that judgments and explanations arise from the same underlying knowledge—the causal principles. We

have also argued that the production of explanations may require more than an explicit understanding of the rules or principles that guide causal understanding, and thus may not allow valid assessment of the thinking of the young preschooler. Indeed, there is evidence that children as old as 7 years may judge and justify their judgments according to different criteria (Klayman, 1976).

One could conclude from this that the way to study thinking in young children is to ignore everything they say and become more and more clever in devising nonverbal tests. This approach certainly has merit; it may even be necessary as a means of gaining an initial assessment of the extent of a young child's knowledge. However, the children in the studies we reported did provide explanations and their explanations changed in consistent ways. A full account of causal reasoning must address the issues of how explanations are related to causal judgments and how they change with age.

These are two issues embedded in the above questions. One is to ask whether, or in what ways, children's explanations were "deficient." The second is to ask what sorts of knowledge one must draw on to provide an adequate explanation.

Across the studies, the coding systems used for judging explanations included some specific criteria: explanations were judged as being "better" when they included information about possible mechanisms or intermediary events. In most conditions, this information was not directly seen, but was inferred from the events that were seen. Indeed, it is a concern with mechanism—or the "hows" of causal action—that allows one to distinguish causal from coincidental events. According to Piaget (1974), it is the lack of an assumption of mechanism that allows a child to violate constraints of temporal order, to posit animistic causes, and so on.

We found that the older children were more likely to provide information about inferred mechanisms in their explanations. However, although the younger children's explanations did not often include mechanism information, they were constrained in certain ways. We did not, in any of the studies, find much evidence for the many categories of explanation Piaget (1930) claimed were rampant in precausal thought (e.g., animism, dynamism, etc.). The children in the studies talked about the events they saw. They did not endow the toys with human qualities, although the tasks were structured so that they could have. The experimenters talked about the rabbit "going to sleep" or the jack "jumping." Indeed, the fact that the puppets used in some studies "talked" should have suggested to children that it was acceptable to endow inanimate objects (such as the apparatuses) with human qualities.

Across the studies, the most general change in explanations with age was an increase in the amount of information included in an explanation and the extent to which elements of the events were related to each other, including unseen intermediary events. The youngest children (3-year-olds) tended to "explain" by restating only some portion of the events seen; many of the youngest children

said an event occurred because "it did," merely affirming the event. In contrast, the older children not only stated what happened, but often included an inference linking the events together in time. We should note that the 5-year-olds' responses were remarkably similar to those of adult colleagues who were asked to view, judge, and explain the same sequences.

Certain conditions in the different studies seemed more conducive than others to the production of "good" explanations. Explanations were more integrated, more complete, or more mechanistic in those cases where children either had ready information about possible mechanisms or when they were asked to explain an outcome that was unexpected. To illustrate: children in the Baillargeon *et al.* study showed that when information was available, connections would be mentioned in descriptions and explanations; when it was not, some children could fill in the information, but many did not. This suggests that children may be reluctant to talk about events when they can only speculate as to their content.

The effects of unexpected outcomes is illustrated in the jack-in-the-box studies. Children were more likely to talk of mechanisms when some violation of an unexpected outcome occurred. The proportion of mechanistic explanations was greater for children who saw the unconnected demonstrations than for those who saw the connected trials. Similarly, in the priority study, 4- and 5-year-olds were more likely to be surprised and talk of connections when the unconnected ball preceded the jack's action. These results are consistent with other studies. Berzonsky (1971) reported that children were better able to explain how or why something broke than how it worked. While the same information was relevant in either case, explaining how something worked required choosing which of the many aspects of an event was crucial; explaining how it broke required pinpointing only a single element. This suggests that children's explanations will depend on the complexity of events and on a child's ability to use particular pieces of information, and to gauge the relative importance of one cue over another.

Another reason children's explanations may have been more descriptive than inferential (with respect to mechanism) is that the direct information about the actual events that children saw may be more salient and therefore more easily articulated. That is, children may have had more ready access to the stimulus information than to the principles that guided their attention to these cues. This implies that children's explanations should improve as they become better able to access their implicit causal theories. Given the difficulties preschoolers have in articulating much of anything about their internal mental worlds (cf. Flavell, 1980), it is not surprising that their explanations were less telling of their reasoning abilities than their judgments.

A final issue concerning explanations and judgments focuses on the nature of the explanations themselves. It may be that children have to learn exactly what an acceptable explanation is; thus, their understanding of requests to "explain" may develop with age. In most accounts of causal explanation, it is assumed that there is

PP1 (30).max

a taxonomy of explanation type, arranged from less to more adequate. The better types are those that more closely approximate the ideal of scientific explanation. This includes providing not only the sufficient conditions for an event's occurrence, but the necessary ones as well. Thus, for example, an explanation of why a picture fell from the wall that included information about why one picture fell and another did not would be considered better than an explanation that described merely how the one picture fell.

It may be, though, that this criterion for a mature explanation is a special case, not adhered to in everyday adult explanations. That is, the model of a "good" explanation adopted by the sciences (and by scientists studying causal explanations) may not reflect the ordinary adult's criteria. Depending on the extent of knowledge about a phenomenon, descriptions often suffice as well as statements about necessary and/or sufficient conditions. We would agree, for instance, that to say an apple falls to the ground because of gravity is an adequate explanation. Similarly, to explain the action of an internal combusion engine by describing its components is adequate for most purposes. Finally, to return once more to our irreplaceable, shattered window, we could explain its breaking by referring to a property of glass (it was brittle) or of the cause (the rock was hard). In short, it may not be necessary in everyday explanations to outline the necessary or sufficient causes for an event. Indeed, some current analyses of causal explanations suggest that a *request* for an explanation is a tacit command for information about the unexpected or unusual aspects of a situation (Kahneman, 1980). Thus, the answer "*Because it was brittle*" may be a perfectly reasonable answer to the question "*Why did the window break?*" if there was no reason to expect the window to be bulletproof. Note that such an explanation from a child might be classified as precausal since it refers to a property of an event as causing the event.

Such a characterization of everyday adult explanations would suggest that children's explanations might differ because they know less about the world and, presumably, have a less clear idea about the usual. Without an articulable understanding of the usual, one would have greater difficulty picking out *which* aspects of a situation to include as content for an explanation. This idea could be tested by asking whether children's explanations are more sophisticated when they are asked to explain why familiar events do not occur than when they do. To the extent that they understand the *expected* event, its nonoccurrence might allow them easier access to the basis of their expectations. Similarly, if it is the case that explaining an event involves an ability to reflect upon and articulate one's implicit causal theory, it should be possible to highlight the underlying bases of judgments by showing children events in which the stimulus information predicted by the principles was not available. If these manipulations lead children to explain events in a more "mechanistic" manner, it would suggest that the preschooler's problems in explaining are not so much a failure to *have* causal knowledge as a disinclination to use that knowledge in explaining.

A final way in which children's abilities to explain may depend on more than causal understanding concerns the task of explaining. Psycholinguistic work on children's knowledge of conversational constraints (e.g., Clark & Clark, 1977; Gelman & Shatz, 1977) reminds us that even young preschoolers are sensitive to conversational demands. For instance, one rule that guides adult conversation is "tell only new information." Children who are sensitive to this rule may refrain from fully explaining an event to an adult who also witnessed it. Lloyd and Donaldson (1976) for instance, suggest that if one wants a preschooler to reveal the best of his or her competence, the child should be put in the position of offering information, not merely answering questions.

Similarly, children may be sensitive to the form of the questions they are asked (cf. Nass, 1956). For example, "why" suggests a request for a reason for an event; "how" suggests a mechanism. It may be that children's explanations vary with whether they are asked why or how. A current study by M. Bullock (1981) is designed to test these intuitions. Children are asked to explain several events ranging from simple, mechanical sequences to more complex chains of occurrences. They are queried under one of four conditions, varying who asks the questions and how they are phrased. The question is asked by either an experimenter, who has also witnessed the events, or by a puppet adjunct, who has not witnessed the events. The questioner asked "how" an event occurred or "why" it did so. Preliminary results are straightforward: children's explanations are most likely to be mechanistic, physically oriented, and more complete when questioned by someone who has not seen the event and when asked how something occurred rather than why. Children's sensitivity to these fairly subtle manipulations should caution against interpreting deficient explanation data to reflect deficient reasoning abilities.

SUMMARY AND CONCLUSIONS

We began this chapter with a set of related questions: How are causal events understood and how does this understanding develop? In the course of our investigations, we have begun to fill out a framework that breaks causal reasoning into a hierarchy of components (the principles, knowledge, and use of stimulus information), and that allows us to ask which, if any, of the components change with development.

In this final section we hope to accomplish three things: summarize why we believe that children's understanding of events uses the same implicit principles as adults'; suggest ways in which empirical investigations need to expand on our knowledge of children's thinking; and speak more generally to the questions of causal reasoning across time and space.

We have suggested that causal reasoning is directed by adherence to the

principles of determinism, priority, and mechanism, and that children as young as 3 years possess these principles. This means that the development of causal understanding is more a process of learning where, when, and how to apply the rules of reasoning rather than figuring out what those rules might be. We find support for this notion in several areas.

First, 4- and 5-year-olds consistently chose causes on the basis of information consistent with such principles, and did not choose events that would be inconsistent with the principles. Furthermore, older children, for the most part, articulated the bases of their choices, at least when they explained simple or unexpected events or events about which they were knowledgeable. While the 3-year-olds were not as consistent in their choices and did not explain well, even they showed evidence of reasoning according to the principles in some situations. In the determinism study, the priority study, the rabbit prediction studies, and the picture card study, the 3-year-olds' choices—though not as robust as those of older children—were consistent with the use of underlying causal principles. Unless one provides a simple situation, ample experience with it, and unambiguous response instructions, then, the abilities of the youngest children are not as likely to be evident in their performance.

There is one important point to be made here. We are not implying that preschoolers' causal thinking is identical to adults'. Certainly, there are pervasive and consistent differences. However, we do want to argue that the differences that exist arise not because the child and adult think about things in fundamentally different ways, but because the child's thought is more constrained by context, complexity, and verbal demands, limiting the scope and flexibility with which the child can apply his or her knowledge.

In the introductory sections we outlined three models of how causal principles might arise. Our data now allow us to choose among these models. Neither the empiricist approach nor a structuralist view that denies adult principles to preschoolers can account for responses mediated by the principles of determinism, priority, or mechanism.

Two cases may serve as illustrations of the unambiguous use of principles. First, the Fred-the-rabbit prediction studies offer support for an ability that is not demonstrated by explanations or judgments. Had children not been sensitive to issues of mechanism, they would not have predicted as well as they did, and they would not have differentiated between those modifications that would and would not alter an outcome. Predicting, in contrast to explaining or making a choice between alternatives, may be a simpler task in that one does not need to articulate the basis of a judgment or to consider and choose between alternatives.

Secondly, the studies on the relative use of spatial and temporal information revealed that children's choices between temporal contiguity cues were mixed, or indifferent. We would argue that in this case their indifference arose because all the choices they were given were consistent with the defining principles of

PP1 (30).max

priority and mechanism. Given that, they genuinely had no basis for a differential judgment. This suggests that what may change with development is the use of stimulus information. Children may need to learn that among those events that obey the causal principles, there are variations in direct spatial and temporal properties that provide the means for choosing a cause. This suggests that learning about specific events or types of events will contribute to children's increasing accuracy in choosing a *correct* cause.

The series of studies we have reported here demonstrate an approach that involves analyzing a content area (causal reasoning) into its constituent components, asking whether children's performances reflect an understanding of the components to differing degrees, and asking what does and does not change with development. In arguing that preschoolers show a remarkable competence in reasoning about causal matters, we have also pointed out some areas in which they do *not* show adultlike competence. Notably, their explanations, use of stimulus information, and willingness to speculate about events for which they have scanty particular knowledge all stand in contrast to their robust reasoning according to underlying principles. This suggests that future research should concentrate on three areas: children's understanding of explanations and explaining; children's use of particular stimulus information; and finally, children's abilities to *integrate* the different aspects of causal thinking into a coherent, articulable system.

ACKNOWLEDGMENTS

We thank the children, parents, and staff of the following: Alma Y Day Care, Broadway West Day Care, Beach Day Care, Cedar Cottage Neighborhood Services, and Rainbow's End Day Care, Kits Area Child Care, and False Creek Child Care Society, all of Vancouver; Chestnut House, YM/YWHA Preschool, and Penn Day Care of Philadelphia.

REFERENCES

Ammon, M. S., & Slobin, D. A cross-linguistic study of the processing of causative sentences. *Cognition*, 1979, *1*, 3-17.

Ausubel, D. M., & Schiff, H. M. The effect of incidental and experimentally induced experience on the learning of relevant and irrelevant causal relationships by children. *Journal of Genetic Psychology*, 1954, *84*, 109-123.

Baillargeon, R., & Gelman, R. *Young children's understanding of simple causal sequences: Predictions and explanations*. Presented at the meetings of the American Psychological Association, Montreal, 1980.

Baillargeon, R., Gelman, R., & Meck, E. *Are preschoolers truly indifferent to causal mechanism?* Paper presented at the biennial meeting of the Society for Research in Child Development, Boston, April 1981.

Bassili, J. Temporal and spatial contiguity in the perception of social events. *Journal of Personality and Social Psychology*, 1976, *33*(6), 680-685.

Berzonsky, M. The role of familiarity in children's explanations of physical causality. *Child Development*, 1971, *42*, 705-712.

Bowerman, M. *Reorganizational processes in lexical and semantic development*. Paper presented at a workshop-conference on "The State of the Art" in language acquisition, University of Pennsylvania, May 19-22, 1978.

Brainerd, C. Cognitive development and concept learning: An interpretative review. *Psychological Bulletin*, 1977, *84*, 919-939.

Brown, A. L. Recognition, reconstruction and recall of narrative sequences by preoperational children. *Child Development*, 1975, *46*, 156-166.

Bullock, M. *Aspects of the young child's theory of causation*. Unpublished doctoral dissertation, University of Pennsylvania, 1979.

Bullock, M. *Puppet play: Children's interpretation of causal questions*. University of British Columbia, 1981.

Bullock, M., & Baillargeon, R. *Relative temporal and spatial contiguity in causal judgments*. Unpublished manuscript, University of British Columbia, 1981.

Bullock, M., & Gelman, R. Numerical reasoning in young children: The ordering principle. *Child Development*, 1977, *48*, 427-434.

Bullock, M., & Gelman, R. Children's assumptions about cause and effect: Temporal ordering. *Child Development*, 1979, *50*, 89-96.

Clark, H., & Clark, E. *Psychology and language*. New York: Harcourt Brace Jovanovich, 1977.

Copple, C., & Coon, R. The role of causality in encoding and remembering events as a function of age. *Journal of Genetic Psychology*, 1977, *130*, 129-136.

Dennis, W., & Russell, R. W. Piaget's questions applied to Zuni children. *Child Development*, 1940, *11*, 181-187.

Deutsche, J. M. The development of children's concepts of causal relations. In R. Barker, J. Kounin, & H. Wrights (Eds.), *Child behavior and development*. New York: McGraw-Hill, 1943.

Donaldson, M. *Children's minds*. New York: Norton, 1978.

Flavell, J. *Metacognitive development*. Paper presented at the NATO Advanced Study Institute on Structural/Process Theories of complex human behavior. Banff, Alberta, Canada, June 20-30, 1977.

Gardner, J. *The resurrection*. New York: Ballantine, 1966.

Gelman, R. How young children reason about small numbers. In N. J. Castellan, D. B. Pisoni, & G. R. Potts (Eds.), *Cognitive theory* (Vol. 2). Hillsdale, N.J.: Erlbaum, 1977.

Gelman, R. Cognitive development. *Annual Review of Psychology*, 1978, *29*, 297-332.

Gelman, R., Bullock, M., & Meck, E. Preschoolers' understanding of simple object transformations. *Child Development*, 1980, *51*, 691-699.

Gelman, R., & Shatz, M. Appropriate speech adjustments: The operation of conversational constraints on talk to two-year-olds. In M. Lewis and L. A. Rosenblum (Eds.), *Interaction, conversation, and the development of langugae*. New York: Wiley, 1977.

Gibson, E. J. *Development of knowledge about intermodal unity: Two views*. Paper presented at the Jean Piaget Society Annual Symposium, Philadelphia, May 29-31, 1980.

Gibson, J. J. *The sense considered as perceptual systems*. Boston: Houghton-Mifflin, 1966.

Gruber, H., Fink, C., & Damm, V. Effects of experience on perception. *Journal of Experimental Psychology*, 1957, *53*, 89-93.

Huang, I. Children's conception of physical causality: A critical summary. *Journal of Genetic Psychology*, 1943, *64*, 71-121.

Hume, D. *An inquiry concerning human understanding*. New York: Bobbs-Merrill, 1955. (Originally published, 1748).

Kahneman, D. Personal communication, 1980.

Kant, I. *Critique of pure reason* (N. K. Smith, trans.). New York: St. Martin's Press, 1965.

Kelly, H. The process of causal attribution. *American Psychologist*, 1973, *28*, 107-128.

PP1 (30).max

Kendler, H., & Kendler, T. From discrimination learning to cognitive development: A neobehavioristic odyssey. In W. K. Este (Ed.), *Handbook of learning and cognitive processes*. Hillsdale, N.J.: Erlbaum, 1975.

Klayman, J. *Judgment and justification in concept development: The case of animism*. Paper presetned at the biennial meeting of the Society for Research in Child Development, San Francisco, May 1979.

Koslowski, B. *Learning about an instance of causation*. Unpublished manuscript, Cornell University, 1976.

Koslowski, B., & Snipper, A. *Learning about an instance of non-mechanical causality*. Unpublished manuscript, Cornell University, 1977.

Kuhn, D., & Phelps, H. The development of children's comprehension of causal direction. *Child Development*, 1976, *47*, 248-251.

Kun, A. Evidence for preschooler's understanding of causal direction in extended causal sequences. *Child Development*, 1978, *49*, 218-222.

Laurendau, M., & Pinard, A. *Causal thinking in the child*. New York: International Universities Press, 1962.

Lesser, H. The growth of perceived causality. *Journal of Genetic Psychology*, 1977; *130*, 143-152.

Lloyd, P., & Donaldson, M. On a method of eliciting true-false judgments from young children. *Journal of Child Language*, 1976, *3*, 411-416.

Mandler, J. Categorical and schematic organization in memory. In C. R. Puff (Ed.), *Memory, organization and structure*. New York: Academic Press, 1978.

Mandler, J. *The construction of knowledge in the child*. Paper presented at the Jean Piaget Society Annual Symposium, Philadelphia, May 29-31, 1980.

Mendelson, R., & Shultz, T. Covariation and temporal contiguity as principles of causal inference in young children. *Journal of Experimental Child Psychology*, 1976, *22*, 408-412.

Michotte, I. *The perception of causality*. New York: Basic Books, 1963.

Mogar, M. Children's causal reasoning about natural phenomena. *Child Development*, 1960, *31*, 59-65.

Nass, M. L. The effects of three variables on children's concepts of physical causality. *Journal of Abnormal Social Psychology*, 1956, *53*, 191-196.

Neisser, U. *Cognition and Reality*. San Francisco: Freeman, 1976.

Nisbett, R., & Ross, L. *Human inference: strategies and shortcomings of social judgment*. Englewood Cliffs, N.J.: Prentice-Hall, 1979.

Olum, V. Developmental differences in the perception of causality. *American Journal of Psychology*, 1956, *69*, 417-423.

Piaget, J. *The child's conception of physical causality*. London: Rutledge & Kegan Paul, 1930.

Piaget, J. *The construction of reality in the child*. New York: Basic Books, 1954.

Piaget, J. *Understanding causality*. New York: Norton, 1974.

Piaget, J. *The grasp of consciousness*. Cambridge, Mass.: Harvard University Press, 1976.

Premack, D. *Intelligence in ape and man*. New York: Wiley, 1976.

Schank, R. A., & Abelson, R. *Scripts, plans, goals and understanding*. Hillsdale, N.J.: Erlbaum, 1977.

Shultz, T., & Mendelson, R. The use of covariation as a principle of causal analysis. *Child Development*, 1975, *46*, 394-399.

Siegler, R. Defining the locus of developmental differences in children's causal reasoning. *Journal of Experimental Child Psychology*, 1975, *20*, 512-525.

Siegler, R., & Liebert, R. Effects of contiguity, regularity and age on children's causal inferences. *Developmental Psychology*, 1974, *10*, 574-579.

Wilde, J., & Coker, P. *Probability, spatial contact and temporal contiguity as principles of causal inference*. Unpublished manuscript, Claremont Graduate School, 1978.

PP1 (30).max