LEARNING AND THE INFANT MIND

Edited by

Amanda Woodward
and Amy Needham

OXFORD
UNIVERSITY PRESS
2009

Introduction

AMY NEEDHAM, DUKE UNIVERSITY; AND
AMANDA WOODWARD, UNIVERSITY OF MARYLAND

This book is the product of a small conference that the two of us organized in May 2005. The conference, on the Duke University campus, consisted of a wonderfully stimulating two days of talks and posters. Our goals in organizing the conference were many, and they are now the goals that we have for anyone (student, faculty, or others) who might pick up this book. We set out as our goals:

1. Encouraging those investigating infants' conceptual knowledge to focus on the mechanisms that give rise to this knowledge, and, in particular, to consider the role of learning in this process.
2. Encouraging those investigating infant learning to focus on the implications of these processes for questions of infants' conceptual structure.
3. Opening and enriching lines of communication among researchers who are conducting cutting-edge investigations into infant learning and infants' conceptual structure.
4. Achieving consensus on appropriate terminology, and, more generally, grounding discussions in a common set of questions so as to work toward productive debates.
5. Encouraging young researchers and students to consider these questions in their own work.
6. Communicating to the broader research community the insights gleaned from this effort.

Thus, our goals were to bring together researchers from diverse areas in the study of infant learning and infant cognition in order to move toward a more general understanding of the role of learning in infant cognitive development. Much

of the work on infant cognition has focused on investigating infants' knowledge in core domains but has not thoroughly investigated the factors that contribute to the growth of this knowledge. Recent research elucidating rich learning processes in infants offers a vantage point from which to address this gap and thereby address a number of unresolved issues concerning the nature of the infant mind.

BACKGROUND AND RATIONALE FOR STUDYING INFANT LEARNING

Psychologists have long understood the importance of learning to the human mind. The hallmarks of human thought—among them cognitive flexibility, scientific discovery, and the existence of variations in systems of belief across cultures—are clear demonstrations that the mind is structured, and restructured, by information gleaned from the environment. Learning is evident at all levels of information processing, from the fine-grained dynamic tuning of perceptual and motor systems to the environment (e.g., Gibson & Gibson, 1955) to the acquisition of knowledge in abstract domains, including language, cultural beliefs, and both folk and formal scientific systems (e.g., Gentner & Medina, 1998). It is also evident at all points in the human lifespan.

It seems obvious to consider learning when asking how cognition comes to take its mature form. And, indeed, developmental psychologists have long considered this issue. However, until very recently, there has been limited exploration of learning as a mechanism of conceptual development during infancy. One major line of research on infant cognition has focused on the basic knowledge systems that subserve human thought, investigating infants' conceptual knowledge in these domains. To illustrate, investigators have asked whether infants apprehend the physical permanence of objects, the causal relations between objects, and the intentions that give rise to actions. These researchers are deeply concerned with conceptual structure in infants, but they often have not considered the ways in which learning may contribute to this structure. Another major line of research has focused on infants' perceptual and motor learning. These researchers have focused on how infants extract information from the environment, tune their behavior patterns according to this information, and generalize learning to new situations. These researchers have been deeply concerned with elucidating learning mechanisms but often do not consider the potential effects of these mechanisms on conceptual structure. We held this conference to promote the integration of investigations of infant conceptual structure and infant learning, facilitating communication between these two groups of researchers and thereby moving toward a unified framework for understanding infant cognition.

THE ROLE OF LEARNING IN DEVELOPMENT

Adaptability is a hallmark of human cognition, setting our species apart from others. This adaptability results, in part, from the complexity of human learning.

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Therefore, understanding the process and contents of learning is critical for understanding human nature. We believe that a full understanding of a process is possible only after examining its origins and development.

In the context of development, learning has been considered from two vantage points. One classic theoretical position has considered learning to be the backbone of development (e.g., Munn, 1946; Siegler, 2000). In this view, the complexity, flexibility, and variability of mature functioning are directly explainable as the products of learning. Learning is evident from the earliest points in human ontogeny, and research has long underscored the uniformity of processes that contribute to learning across the lifespan (Munn, 1946; Rovee-Collier & Barr, 2001). Indeed, researchers have made important strides in elucidating the learning mechanisms that contribute to conceptual development during childhood (e.g., Gentner & Medina, 1998; Samuelson & Smith, 2000; Siegler, 2000; McClelland & Siegler, 2001).

In contrast, a second classic position points out the insufficiency of learning as a mechanism to explain the emergence of mature cognition (e.g., Piaget, 1954). There are two main arguments in favor of this position. First, it has been suggested that the information available to children is in principle insufficient to support the extraction of regularities that children come to represent (Spelke, Breinlinger, Macomber, & Jacobson, 1992; Pinker, 1994). Second, it has been noted that there are strong limits on what children can learn at particular points in development (e.g., Piaget, 1954). For these reasons, it is argued that the complexity, generality, and flexibility of mature cognition exist, in large part, because of internal constraints on how children represent information.

Resolutions between these two driving intuitions are possible. Indeed, most researchers believe that development is the product of interactions between structure in the organism and structure in the environment, and the real questions concern the nature and unfolding of these interactions. What can be learned at any point in development is constrained by structure in the learner. Learning could, in principle, render changes in this structure, thereby constraining subsequent learning. However, in the field of infancy research, there has been an unfortunate tendency to polarize these two views about the explanatory power of learning. Moreover, these two views have been conflated with assumptions about the nature of cognition in infants. Researchers who posit little explanatory power for learning also tend to posit the existence of rich and relatively abstract systems of knowledge in infants. Researchers who posit a great deal of explanatory power for learning also tend to posit the absence of rich and relatively abstract knowledge in infants. This conflation has led to a neglect of the role that learning plays in infant cognitive development, and, more generally, to a neglect of the complex organism–environment interactions that contribute to cognitive development in infancy.

INFANT COGNITION

Twenty years of research has provided strong evidence that infants possess structured knowledge that informs their responses to novel events. This knowledge

is evident in studies of infants' representations of objects (Clifton, Rochat, Litovsky, & Perris, 1991; Spelke et al., 1992; Xu & Carey, 1996; S. Johnson, 1997; Wilcox, 1999; Baillargeon, 2002), causal relations (Leslie, 1982, 1984; Leslie & Keeble, 1987; Oakes & Cohen, 1990; Kotovsky & Baillargeon, 1998; Schlesinger & Langer, 1999; Kotovsky & Baillargeon, 2000), quantity (Wynn, 1992; Brannon, 2002; Feigenson, Carey, & Spelke, 2002; Mix, Huttenlocher, & Levine, 2002), space (Hermer, & Spelke, 1994; Kaufman & Needham, 1999; Newcombe & Learmonth, 1999), categories (Mandler, 1998, 2000; Quinn & M. Johnson, 2000; see Rakison & Oakes 2003), and intentional action (Gergely, Nadasdy, Csibra, & Biro, 1995; Meltzoff, 1995; Woodward, 1998; Baldwin & Baird, 2001; Kuhlmeier, Wynn, & Bloom, 2003). In each case, infants have been shown to perceive and respond to the components of an event in terms of conceptually important dimensions. These findings emerge from studies using a range of methodologies, including paradigms assessing infants' visual attention and paradigms assessing infants' organized actions on objects and their interactions with social partners.

In almost all cases, these studies investigate what infants know but not how they come to this knowledge. Indeed, especially when researchers uncover systematic responding in very young infants, the conclusion is often drawn that this responding reflects innately specified knowledge. Researchers have been deeply concerned with gaining a clear view of infants' knowledge at a particular point in time and, therefore, typically test "snapshots" of infants' representations at a point in time rather than assessing how these representations may change as a function of experience. This is an important first step in a developmental research program because it can establish a skeletal outline of the shape of development and nominate certain kinds of experiences as likely contributors to developmental change. But this is only the first step in understanding development.

Moreover, considering learning may help resolve current debates concerning the nature of infant cognition. For one, there is not yet a general consensus about the processes that give rise to infants' attention to the conceptually relevant aspects of experimentally presented events or how these processes and the resulting knowledge develop. One debated issue is the extent to which infants' mental representations are limited to stored perceptual regularities rather than including forms of knowledge that are more abstract. A second set of issues concerns the extent to which infants' knowledge is tied to particular behavioral contexts rather than being accessible across response modalities, and the related question of when and whether there are dissociations between the knowledge expressed in different kinds of actions (e.g., in the deployment of visual attention versus in motor behavior). In addition, there are open questions concerning the developmental mechanisms that underlie infant cognitive development. Developmental mechanisms include the emergence of symbolic thought, perhaps a result of the emergence of language; the strengthening of initially weak representations; and the integration of previously isolated pockets of knowledge.

Considering the role of learning in infant cognitive development will provide a foothold for addressing the following issues. How infants extract information from experience and generalize it to new instances directly informs conclusions

about how abstract and modality-general infants' knowledge is. The acquisition of new or novel information may be particularly informative in this regard. By discovering what infants *can* learn based on particular kinds of experiences, we can elucidate the processes that likely contribute to cognitive development. Moreover, by discovering what infants *can't* learn as readily, we can begin to determine how the structure of the learner constrains development at particular moments in ontogeny. The extents to which infants generalize information along some dimensions and not others, resist learning violations of entrenched regularities, and acquire some kinds of information more quickly than others all provide insight into the potential constraints (established either during phylogeny or ontogeny, in the latter case, perhaps by prior learning) that govern development. Concordance between changes in learning and other potentially important developmental events (e.g., the emergence of language or the development of inhibitory mechanisms) will inform theories of how these changes might contribute to cognitive development. More generally, to really understand infants' cognitive functioning, we need to understand the process(es) by which they acquired their knowledge. This requires making connections between what infants seem to know and how they acquired that knowledge. Making these connections is important because we may well find commonalities across domains of study that have typically not been integrated.

For these reasons, we believe there is much insight yet to be gained about infant cognitive development by taking a closer look at the processes by which cognitive abilities change with development. As a result, we wish to bring learning to the forefront of thinking for researchers who are interested in infants' conceptual knowledge and to highlight questions concerning infants' conceptual knowledge for those who study infant learning. Because debates about the nature of infant cognition have often been expressed in disagreements about the terms that are used to describe infant knowledge (compare Baillargeon, 1999, and Smith, 1999; also Haith, 1998, and Spelke, 1998), we hope to get discussion started on the meanings of terms that are often used to refer to cognitive functions in infants.

PLAN FOR THE BOOK

Historically, infant learning was studied in the context of classical and operant conditioning (e.g. Brackbill, 1958; Lipsitt, 1967; Clifton, 1974; Rovee-Collier, 1986). In part, infant-cognition researchers turned away from learning because these mechanisms seemed unlikely to yield insights into cognitive development. However, researchers of various aspects of infant development have begun to take a new look at learning and have documented that infants' repertoire of learning tools is richer than once thought. The relevant research is spread across diverse domains. In each case, researchers have begun to document infant learning in the laboratory. These experimenters introduce infants to new information and then track the ways this information is encoded and subsequently integrated into infants' cognitive functioning.

SUPPORTING LEARNING: ATTENTION, PERCEPTION, MEMORY, AND NEURAL PROCESSES

Learning occurs in a system in which perception, attention, and memory interact. Much has been learned in recent years about the development of these processes during infancy. We know that even fetuses have some capabilities in each of these areas, although many improvements do occur during the first several years of life. Research has investigated the characteristics of objects and events that tend to draw and keep infants' attention, and the relation between shifts in attention and changes in heart rate (Ruff, 1984; Richards & Casey, 1991). Perception of objects is reasonably accurate but non-inferential during the newborn period, with major improvements in acuity, color vision, and interpretive functions between birth and six months of age (for reviews, see S. Johnson, 1997; Kellman & Banks, 1998; Needham, 1998; Slater, 1998; Teller, 1998). Memory is also improving dramatically during the first year of life, although even fetuses show evidence of learning and remembering for short periods of time, with retention intervals systematically increasing with gestational age both before and after birth (e.g., Slater, Mattock, Brown, Burnham, & Young, 1991; DeCasper, Lecanuet, Busnel, Granier-Deferre, & Maugeais, 1994; Krueger, Holditch-Davis, Quint, & DeCasper, 2004). There is good evidence for implicit, "pre-explicit," and explicit memory developing during the first year of life, with the nature of the event (is there a clear causal structure or not) and language (language-based representations are thought to be qualitatively different from pre-linguistic representations) exerting important influences. Recent work has begun to shed light on the brain structures responsible for each of these advances (M. Johnson, 1997; Diamond, 2000; Nelson, 2002; Bauer, 2004). Infants must be capable of perceiving and remembering objects, and of integrating their experiences into knowledge structures if they are to learn from their prior experiences and apply this learning to novel circumstances. Chapter 1 addresses issues of learning, memory, and consolidation, and Chapter 3 discusses the early development of object perception.

LEARNING ABOUT OBJECTS AND ACTIONS

How do infants come to understand and predict the physical movements that the objects in the world, including their own body, will undergo? This question has motivated various lines of research, with investigators asking how infants perceive and represent objects, focusing on what sources of information are useful in these tasks, and considering how we should think about the interactions between more concrete and more conceptual kinds of information in these tasks (Xu & Carey, 1996; S. Johnson, 1997; Needham, 1998, 1999; Wilcox, 1999).

Infants' expectations about how objects interact with each other have been studied somewhat extensively although, as noted earlier, much more is known about what infants know at a variety of ages than about how infants go from one kind of understanding to another. However, there are some notable exceptions. For example, Baillargeon (1999, 2002) has shown that contrastive evidence—seeing

the results of a violation and a fulfillment of a physical principle—is particularly important to infants' learning of physical principles.

Also important in this area of research is specificity in infants' learning: Infants seem to learn separately about the movements of physical objects and the movements of a very complicated "object": the infant's own body (Adolph, 1997). Infants learn separately about occlusion and containment events involving inanimate objects, and they learn separately about the limits of their own body while crawling and while walking (Adolph, 1997; Hespos & Baillargeon, 2001). Other findings on motor development support these general claims (Goldfield, Kay, & Warren, 1993; Thelen, Corbetta, Kamm, Spencer, Schneider, & Zernicke, 1993; Diamond, 2000).

Together, these two lines of research suggest that learning from the environment about the movements of objects or people is a grassroots effort in which experiences may be grouped together based on critical but superficial similarities between them (e.g., removal of support leads to an object's falling down; crawling versus standing posture creates very different vantage points on the situation). Over time, generalization across different pockets of knowledge must occur and is an important process to understand for both of these kinds of learning about the world.

In this volume, Chapter 4, Chapter 5, Chapter 7, and Chapter 8 discuss the relations between objects and actions in a learning context. Chapters 4, 5, and 8 discuss how infants learn about the physical world (i.e., the world of objects) and how their own experiences and other cognitive processes (e.g., categorization, judgments of perceptual similarity) play a role in this learning. Chapters 7 and 8 discuss the ways in which infants' learning to move their bodies looks very much like other kinds of learning that infants do.

LANGUAGE LEARNING

In many ways, the language domain is a model for the productive study of infant learning. Recent research has brought many aspects of language learning into the infant laboratory—from the extraction of the phonemic categories of one's native language (Kuhl, 2000; Maye, Werker, & Gerken, 2002; Werker & Tees, 2002) to the extraction of linguistic units from the speech stream (Saffran, Aslin, & Newport, 1996), to the linking of form with meaning (Woodward, Markman, & Fitzsimmons, 1994; Stager & Werker, 1997; Gogate, Walker-Andrews, & Bahrick, 2001; Smith, Jones Landau, Gershkoff-Stowe, & Samuelson, 2002; Booth & Waxman, 2003), to the acquisition of grammar (Gomez & Gerken, 1999; Marcus, Vijayan, Bandi Rao, & Vishton, 1999; Gomez & Gerken, 2000). For each of these diverse aspects of language learning, researchers have established paradigms for directly investigating learning in the laboratory. These experiments have revealed that a range of learning processes contribute to language acquisition, including perceptual learning—the refinement of perceptual categories based on the distributional properties of the input; statistical learning—the extraction of units from unsegmented speech via the computation of transitional probabilities; rule learning—the acquisition of rules from observed regularities, and associative learning.

Across these processes, researchers find that the products of learning can be relatively abstract in nature. To illustrate, Marcus and colleagues (1999) report that eight-month-old infants who are exposed to the pattern A-B-A in a series of nonsense syllables recognize this pattern when they later encounter it in novel sequences. That is, infants seemed to have stored not just the particular sound sequences they had heard but also the abstract pattern that gave rise to them. The products of learning can also be generative, providing the basis for future acts of learning. For example, statistical segmentation of speech sounds yields units that can be co-opted for word learning (Saffran, 2001), and an infant's prior experiences mapping words to meanings shapes their expectations about the likely meanings of new words (Smith et al., 2002).

A cross-cutting debate concerns the extent to which infants' language learning can be explained via general mechanisms rather than via language-specific learning mechanisms (e.g., Tomasello, 2001; Lidz et al., 2003). Indeed, several of the learning processes initially identified in the context of infant language learning seem likely to have much broader application. To illustrate, Baldwin and Baird (2001) suggested that statistical-unit extraction may provide the basis for infants' detecting behavioral regularities in the actions of social partners.

Chapter 2 and Chapter 10 describe different perspectives on the learning mechanisms underlying language development, including statistical learning mechanisms and situational factors that may support word learning.

CONCEPTUAL LEARNING

Central to any act of learning and generalization is (1) the detection of differences across individual instances and (2) the identification of correspondences or commonalities across these instances. Several decades of research have elucidated infants' ability both to extract differences and to notice at least some commonalities that allow for the formation of perceptual categories. Across these studies, infants manifest a sensitivity to category structure in their patterns of attention (see Quinn, 2002; Rakison & Oakes, 2003). Like adults, infants appear to structure their categories around a prototype. And over the course of the first year of life, infants come to attend not only to individual features but also to correlations among features in doing so (Cohen, Chaput, & Cashon, 2002). Infants, like adults, categorize more efficiently when given the opportunity to compare members of a category to one another or to members of a contrasting category (Oakes & Madole, 2003). By the end of the first year, infants have moved beyond the perceptual commonalities that unite categories. They infer that members of a kind share properties that are not immediately observable. By the end of the first year, infants begin to understand the link between conceptual categories and language: Hearing diverse members of a kind labeled with the same name leads infants to seek out commonalities among them (Waxman, 2003).

In recent years, researchers have asked about the relation between perceptual and conceptual representations of categories. Some have proposed strong discontinuities between perceptual and conceptual categories, either because the

two systems are proposed to exist independently from early in life (Mandler, 1998) or because conceptual representations are proposed to depend on the emergence of new cognitive capacities and/or language (Xu & Carey, 1996; Quinn, 2002). However, others have proposed that increasingly abstract category knowledge grows from early perceptual categories and the processes that give rise to them (Oakes & Madole, 2003; Rakison, 2003). In this view, learning contributes centrally to the formation of conceptual knowledge in infants.

Although even infants have been shown to identify commonalities across different instances of a category that has at least some perceptual support, other commonalities are more difficult to appreciate. For instance, the correspondence between a symbol and its referent (e.g., a room and a scale model of that room) are not understood until sometime between two and three years of age (DeLoache, 1987, 2004). A genuine appreciation of the relation between a symbol and its referent (perhaps especially the unique relation between a model and the space it represents) may require more conceptual ability than most infants and very young children typically possess. As we write, the perceptual and conceptual contributions to the ability to symbolize are still being investigated, with many interesting questions yet to be answered.

Chapter 6 and Chapter 11 discuss the role of learning in categorization and symbolization abilities early in life. Both chapters highlight the importance of perceptual support, especially early in the development of these skills.

SOCIAL LEARNING

Researchers have long understood the foundational role of social partners in structuring development (e.g., Harlow & Zimmerman, 1959), and recent studies have begun to bring infant social learning into the laboratory to investigate the processes by which it occurs. One process, initially identified by Bandura, Ross, and Ross (1963) in older children, is learning by reproducing the observed actions of social partners. Forms of imitative learning are present from birth (Meltzoff & Moore, 1977; Heimann, 2002). By 9 to 12 months, imitative learning is robust across a range of situations, and the products of learning can be sustained for weeks or even months, even when infants lack the opportunity to reproduce the observed action in the intervening period (Collie & Hayne, 1999; Meltzoff, 2002; Bauer, 2004). Imitative learning yields a range of cognitive products, including not only procedural knowledge but also conceptual representations of the relevant objects and events (Bauer, Hayne) and possibly information about the goals that drive action (Meltzoff, 2002). Recent findings documenting neurocognitive mirroring systems in adults suggest a possible basis for imitative learning in infants (see Meltzoff & Prinz, 2002), but it is also clear that general memorial processes, and top-down constraints on event representation, contribute to infants' learning from the observed actions of other people (Bauer & Mandler, 1992; Meltzoff, 1995; Gergely, Bekkering, & Kiraly, 2002). Critically, infants' learning from social partners is mediated by their emerging knowledge about the intentional structure of action, not only in the case of imitative learning (Meltzoff, 1995;

Gergely et al., 2002) but also in language learning (Tomasello, 1999; Baldwin & Moses, 2001; Woodward, 2003) and social referencing (Moses, Baldwin, Rosicky, & Tidball, 2001). To illustrate, by 14 to 18 months, infants use behavioral evidence of a speaker's attention and purposefulness to determine which of several objects is the intended referent (see Tomasello, 1999; Baldwin & Moses, 2001, for reviews). Thus, in this domain, researchers have begun to investigate the ways that social knowledge is generative, building on itself in development.

In this volume, Chapter 9 delves into intriguing new ideas about how infants learn about people, knowledge that helps infants understand what people are doing in the present and predict what they will do in the future.

INTEGRATION

At the conference, we were very fortunate to have the involvement of a number of senior scholars who provided a valuable integrative force to our discussions. This was especially important because we had solicited presentations about a wide range of topics. In this volume, our last chapter is an integrative piece written by Dick Aslin. Dick was one of our advisers during the conference, and he agreed to reprise his role in written form here in our book. He read all of the chapters and crafted a beautiful document that helps us see both where we have been and where we need to go.

CONCLUSIONS

Across all of these domains, three trends indicate that the time is right to move to a more general understanding of the role of learning in infant cognition.

1. Researchers have begun to consider whether and how the products of learning "go beyond" the input, in several senses. First, they have begun to investigate whether infants derive relatively abstract representations from experience. Second, they have begun to investigate the extent to which infants generalize (or fail to generalize) information learned in one behavioral context to a new behavioral context. Third, they have begun to investigate the extent to which learning is generative—constraining and informing subsequent learning.
2. Researchers have begun to elucidate the general and the more specific processes that subserve or contribute to learning and cognitive development, and the ways in which these processes may change with development.
3. There is now a more generally recognized need for consistency in terminology across domains. When this research was in its earliest stages, researchers tended to use terms that were idiosyncratic to their own domains of study. Now the field has progressed to the point that more consistency in the ways in which cognitive terms are used to refer to infant development are absolutely necessary if the field hopes to move forward constructively.

Whether you are a beginning student, an advanced student, or a researcher, we hope you will gain a new appreciation for the relations between what we know about infant cognition and what we are discovering about infant learning. Specifically, we are very excited about the ways in which learning can help transform our snapshot-based characterization of infant development into a vivid Technicolor movie of the infant mind. At present, we can only speculate about how the infant, the learning processes, the structured physical world, and the people in that environment work together to produce the fascinating movie that is the developing infant mind.

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