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THE DEVELOPMENT OF SCIENTIFIC THINKING SKILLS

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PREFACE

The impetus for this book was our desire for a satisfactory framework in terms of which changes in scientific reasoning strategies from middle childhood to adulthood might be conceptualized. The pioneering effort in this respect by Inhelder and Piaget has three significant drawbacks, each of which has led to a diminishment of its influence. The first is the central role that propositional logic plays in their model, and the second the dominating role played by the concept of stage. Cheng, Holyoak, Nisbett, and their colleagues have made a convincing case against the utility of formal logic as a model of thinking, as we discuss in Chapter 2. The concept of stage has proven equally problematic. Little evidence exists to support the presence of global stages in the strong sense that Piaget and Inhelder portrayed them, though, unfortunately, this fact has led many developmentalists to swing to the opposite, and equally unlikely, extreme of maintaining that developmental change is entirely localized. Third, there has arisen an increasing awareness that thinking occurs in a context that significantly shapes its form and expression, and these contextual factors are not ones that formal structural theories of development readily accommodate.

Despite the drawbacks of their theoretical model, an evolution in thought along the lines that Inhelder and Piaget attempted to characterize is of crucial theoretical importance. Are the cognitive processes of exploration and induction significantly different in the child, the adolescent, the lay adult, the scientist? If so, we wondered, is there a useful framework in which such development might be conceptualized and examined?

A recent line of research that reflects a recognition of context is the work on conceptual change and the development of scientific understanding, which we consider in Chapter 2. This work has fostered recognition of the fact that an individual's existing knowledge of the world is organized into mental models, or theories, that provide the context for the assimilation of new information and undergo repeated revision. In many ways, this body of work provided a starting point for the research and ideas presented in this volume. The conceptual change literature, however, has thus far focused on identifying and describing these conceptual structures themselves and has not addressed the mechanisms in terms of which conceptual change occurs. If the revision of theories underlies cognitive development, we need to know more about how it occurs.

The question we posed, then, was how existing knowledge is reconciled with new information, or—in the terminology we use—how existing theories are coordinated with new evidence. The central thesis advanced in this volume is that these processes undergo developmental change—that the strategies used by the young child to reconcile naïve theories and new evidence differ significantly from those used by the more sophisticated thinker. This thesis distinguishes the present work from that of the conceptual change researchers, who tend to argue against strategic change. One of the things we shall suggest is that the metaphor of child as scientist, while useful in one sense, may be fundamentally misleading in another: Theory and evidence—the alleged hallmarks of science—are conceived only in a very restricted sense by the young child.

We have framed the present work in the context of scientific thinking and its development, arguing that skills in the coordination of theories and evidence are the most central and fundamental skills that define scientific thinking. Yet, it is in the context of children and adults as intuitive scientists in everyday life that our work probably has the greatest significance. At the same time, the theoretical framework that we propose offers a way to conceptualize the relationship between thinking in formal scientific and everyday contexts.

A final goal we have for the present work is to provide empirical data of value to the burgeoning group of researchers and practitioners concerned with teaching thinking skills. Too often, in our view, identification of the thinking skills that become the object of an instructional program is based on armchair analysis of the kinds of thinking skills the program creator believes it would be good for students to have. Very little program development has been based on empirical data regarding specific thinking skills that students do (or do not) display in their own thinking, and, most important, *the directions in which such skills develop naturally.*

The present work began when the two junior authors and the senior author were in a student–teacher relationship, but the collaboration and the development of ideas have extended beyond that context. All of the people whose names appear on the title page contributed to establishing an intellectual environment in which the working and reworking of ideas flourished. Early on in the work we decided to publish the series of studies as a book rather than submit them to journals for publication as individual articles; we wanted the reader to be able to regard them within the context of the broader theoretical framework we were developing and in relation to one another. All of these studies were carried out

without external funding, which means the students involved labored without the reinforcements of either money or journal publication. During the course of the work Eric Amsel and Bonnie Leadbeater received support from Canada Council doctoral fellowships. Incidental expenses and the support of the senior author were provided by a small private foundation whose president showed unwavering confidence, for which the senior author will always remain grateful. The senior author's discovery of the powers of the microcomputer also played no small role in the production of this volume. Finally, we are grateful to those who read and commented on drafts of the manuscript; in particular we want to acknowledge the comments of Jonathan Baron, which extended well beyond the routine.

Deanna Kuhn
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INTRODUCTION

Deanna Kuhn

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THE DEVELOPMENT OF SCIENTIFIC THINKING

While the teaching of thinking skills has become a topic of widespread interest and concern, science educators have long been in agreement that a major goal of science education ought to be fostering skills of scientific thinking (Bredderman, 1985; Shymansky, Kyle, & Alport, 1983). Implementation of this goal, however, has been constrained by the very limited body of research data identifying the specific nature of such skills. The purpose of the present work is to investigate the nature and development of some basic scientific thinking skills, specifically the thinking skills involved in the coordination of theories and evidence. A central premise underlying science is that scientific theories stand in relation to actual or potential bodies of evidence, against which they can be evaluated. Reciprocally, scientific "facts" stand in relation to one or more actual or potential theories that offer a vehicle for their organization and interpretation. While we would not want to make the claim that they encompass all aspects of scientific thinking, skills in coordinating theories and evidence arguably are the most central, essential, and general skills that define scientific thinking. A high level of mastery of such skills is assumed not only in the conduct of formal scientific inquiry but in a wide range of other skilled endeavors, such as medical diagnosis (Elstein, Shulman, & Sprafka, 1978) or legal practice (Kassin & Wrightsman, 1985).

Skillful coordination of theory and evidence entails a complex interplay. While existing theories provide the basis for interpretation of new information, new information ideally is attended to and utilized as a basis for evaluating and revising theories. Skillful coordination of theory and evidence also entails a high degree of metacognitive function, that is, reflection on one's own cognition. The proficient scientific thinker presumably can say the following: "I am aware of and can reflect on the theory in terms of which I understand a phenomenon. I can conceive of alternative theories that might explain the same phenomenon, and I understand that they differ from my theory. I can contemplate evidence, and I can evaluate how it bears on both my own and alternative theories, drawing on rules of inductive inference that I am aware of and able to apply. I can recognize and acknowledge discrepancies between theories and evidence, and, based on such discrepancies, I can contemplate revision of a theory." We make no claim here that an idealized portrayal such as this resembles the thinking of professional scientists in their day-to-day activities (Mahoney & Kimper, 1976). Yet if one were to ask any scientist to explain why he or she came to accept a particular theory and reject another purporting to account for the same set of phenomena, it is precisely the set of skills just listed that we would take for granted the scientist had mastery of and would utilize in fulfilling our request.

While the exercise of such skills clearly is cognitively demanding, is it not also true that very simple, common kinds of everyday cognition entail the coordination of theory and evidence? Even the simplest information requires some prior conceptual framework to enable it to be assimilated, which means that new information must in some manner be coordinated with existing theory. Is it possible, then, that at least rudimentary cognitive competencies of the sort indicated are in place early in childhood? Weighing on the side of a positive answer to this question is the growing evidence that beginning with the onset of representational cognition, children encode and represent reality in terms of naïve theories, or scripts, that specify how things work or how events happen. These theories exercise a powerful organizing influence on cognition. In interpreting causal phenomena, for example, young children may overlook violation of fundamental causal cues such as spatial contiguity if they conflict with the child's concept of the causal mechanism involved (Shultz, 1982). With experience, theories are elaborated and revised repeatedly, yielding a sequence of partially correct theories that some theorists have suggested is the heart of cognitive development (R. Glaser, 1984).

Though naïve and sophisticated representations, or theories, of phenomena have been the subject of considerable research attention in recent years (Gentner & Stevens, 1983), very little attention has been paid to the *process* of theory revision, in either adults or children. While children undoubtedly revise their theories as their experience increases, young children are notoriously weak in reflecting on their own thought, and it is unlikely that their theory revision is based on the kind of reflective cognitive processing portrayed above. How, then, does the ability to coordinate theory and evidence, an ability likely to be present among even very young children, develop into the sophisticated form characteristic of mature scientific thought?

Before turning to the research we have undertaken on this topic, it is worthwhile to make explicit several aspects of our methodological orientation, for it differs in two major respects from those currently most common in cognitive development research. A major focus of research effort in the field of cognitive development in the last decade has been identification of the developmental origins of cognitive competencies. If tasks are presented in familiar, facilitative contexts, stripped of extraneous demands, or if minimal training is provided, how early in life can particular cognitive competencies (notably those associated with Piaget's stage of concrete operations) be identified (Gelman & Baillargeon, 1983)? A second focus of research attention has been the role of a developing domain-specific knowledge base. The development of cognitive skills, it has been argued, is most profitably investigated within content-rich, domain-specific contexts (R. Glaser, 1984). At a minimum, the growing knowledge base interacts with skill development; more radically, it is proposed that cognitive development consists entirely of changes in domain-specific knowledge (Carey, 1985a; Keil, 1984), with the implication that attainments within a domain proceed to a large extent independently and show little or no generality across domains.

The present research departs from these two current research thrusts in the field of cognitive development—identifying the origins of cognitive competencies and the role of domain-specific knowledge—though in a way that we believe enriches rather than contradicts them. In the present work we undertake to identify and examine thinking skills assumed to be of some generality across a wide range of content (rather than tied to a specific knowledge domain). Assertions (for example by Keil, 1984) that there presently exists no conclusive evidence documenting the existence of general cognitive skills are probably fair. At the same time, it is also fair to say that existing research is not adequate to decide the matter and that it would be premature to foreclose the possibility that cognitive skills of some generality can be identified. The issue of generality versus domain-specificity of thinking skills is in fact a complex, rather than an either-or, one (Baron, 1985; Levin, 1986). It is very unlikely that thinking skills are either entirely general or entirely domain specific. Moreover, the question can be posed in at least three different forms, one developmental, one conceptual/analytic, and one instructional: (a) To what extent does the acquisition of thinking skills take place in a general versus domain-specific manner? (b) Once skills are acquired, even if in highly domain-specific contexts, are these skills identifiable in more general or only in their domain-specific forms? (c) Should instruction in thinking skills be undertaken in domain-specific or more general form? The working hypothesis adopted in the present research is that most thinking skills emerge and develop in specific contexts and content domains but may nevertheless be identifiable in more general form across domains, even though those using such skills may quite likely themselves be unaware of them in any general form.

The issue of generality/specificity is further complicated by the likelihood that degree of generality versus domain-specificity depends to a considerable extent