INDUCTIVE REASONING

Without inductive reasoning, we couldn't generalize from one instance to another, derive scientific hypotheses, or predict that the sun will rise again tomorrow morning. Despite the prevalence of inductive reasoning, books on this topic are rare. Indeed, this is the first book on the psychology of inductive reasoning in twenty years. The chapters survey recent advances in the study of inductive reasoning and address questions about how it develops, the role of knowledge in induction, how best to model people's reasoning, and how induction relates to other forms of thinking. Written by experts in philosophy, developmental science, cognitive psychology, and computational modeling, the contributions here will be of interest to a general cognitive science audience as well as to those with a more specialized interest in the study of thinking.

Aidan Feeney is Senior Lecturer in Psychology at Durham University. He received his B.A. in psychology from Trinity College, Dublin, in 1992 and completed his Ph.D. at the Center for Thinking and Language at the University of Plymouth. He was appointed Lecturer in the Department of Psychology at Durham University in 1998 and became Senior Lecturer in 2005. Dr. Feeney's research has been supported by a number of grants from the Economic and Social Research Council (UK). He has published approximately thirty journal articles, book chapters, and papers on the psychology of hypothesis testing and reasoning.

Evan Heit is currently Professor of Psychology and Cognitive Science, and Founding Faculty, at the University of California, Merced. Previously, Dr. Heit was on the faculty in the Psychology Department of the University of Warwick, UK. He has undergraduate degrees in computer science and psychology from the University of Pennsylvania and a Ph.D. from Stanford University. He also carried out postdoctoral research at the University of Michigan and Northwestern University. Professor Heit has published more than fifty papers on the psychology of reasoning, memory, and categorization. His research has been funded by the National Science Foundation, the National Institutes of Health, the Economic and Social Research Council (UK), and the Biotechnology and Biological Sciences Research Council (UK). He is currently on the editorial board of *Memory and Cognition* and the *Journal of Experimental Psychology: Learning, Memory, and Cognition* and is Associate Editor of the *Journal of Memory and Language.*

Inductive Reasoning

Experimental, Developmental, and Computational Approaches

Edited by

AIDAN FEENEY

Durham University

EVAN HEIT

University of California, Merced

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List of Contributors

Jennifer Asmuth Department of Psychology, Northwestern University, 2029 Sheridan Road, Evanston, IL 60208-2710, USA

Sergey Blok Department of Psychology, 1 University Station A8000, University of Texas at Austin, Austin, TX 78712, USA

John D. Coley Department of Psychology, MS 0125 NI, Northeastern University, 360 Huntington Avenue, Boston, MA 02115-5000, USA

Aidan Feeney Department of Psychology, Durham University, Queen's Campus, Thornaby, Stockton-on-Tees, TS17 6BH, UK

Ulrike Hahn School of Psychology, Cardiff University, Tower Building, Park Place, Cardiff, CF10 3AT, UK

Brett K. Hayes School of Psychology, University of New South Wales, Sydney, NSW, Australia, 2052

Evan Heit School of Social Sciences, Humanities, and Arts, University of California, Merced, PO Box 2039, Merced, CA 95344, USA

Charles Kemp Department of Brain and Behavioral Sciences, 46-4053, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139, USA

Douglas L. Medin Department of Psychology, Northwestern University, Swift Hall, 2029 Sherdian Road, Evanston, IL 60208-2710, USA

Gregory L. Murphy Department of Psychology, New York University, 6 Washington Place, New York, NY 10003, USA

Mike Oaksford School of Psychology, Birkbeck College London, Malet Street, London, WC1E 7HX, UK

Daniel Osherson Department of Psychology, Green Hall 3-S-12, Princeton University, Princeton, NJ 08544, USA

Bob Rehder Department of Psychology, New York University, 6 Washington Place, New York, NY 10003, USA

Lance J. Rips Psychology Department, Northwestern University, 2029 Sheridan Road, Evanston, IL 60208, USA

Brian H. Ross Beckman Institute, University of Illinois, 405 N. Mathews Ave., Urbana, IL 61801, USA

Patrick Shafto Department of Brain and Behavioral Sciences, 46-4053, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139, USA

Steven Sloman Cognitive & Linguistic Sciences, Brown University, Box 1978, Providence, RI 02912, USA

Joshua B. Tenenbaum Department of Brain and Behavioral Sciences, 46-4015, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139-4307, USA

Paul Thagard Philosophy Department, University of Waterloo, Waterloo, Ontario, Canada N2L 3G1

Anna Vitkin Department of Psychology, MS 0125 NI, Northeastern University, 360 Huntington Avenue, Boston, MA 02115-5000, USA

Sandra Waxman Department of Psychology, Northwestern University, Swift Hall, 2029 Sherdian Road, Evanston, IL 60208-2710, USA

Preface

Books on induction are rare; in fact, you are holding in your hands the first book devoted solely to the psychology of inductive reasoning in twenty years. And yet induction is a central topic in cognitive science, fundamental to learning, discovery, and prediction. We make inductive inferences every time we use what we already know to deal with novel situations. For example, wherever you found this book – in your university library, online, or in an academic bookshop – before picking it from the shelf or clicking on a link, you will have made some inductive inferences. Amongst other things, these inferences will have concerned the book's likely content given its title, its editors, its publisher, or its cover. Common to all of these inferences will have been the use of what you already know – about us, or the topic suggested by our title, or Cambridge University Press – to make predictions about the likely attributes of this book.

It is not only in publishers' catalogues that attention to induction has been scant. Despite its obvious centrality to an understanding of human cognition and behaviour, much less work has been carried out by psychologists on induction than on deduction, or logical reasoning. As a consequence, although there have been several edited collections of work on deduction and on decision making (Connolly, Arkes, & Hammond, 2000; Leighton & Sternberg, 2004; Gilovich, Griffin, & Kahneman, 2002; Manktelow & Chung, 2004), to the best of our knowledge there has never previously been an edited collection of papers on the psychology of inductive inference.

To attempt to redress the balance somewhat, in 2004 we organised a symposium on induction at the Fifth International Conference on Thinking, which was held in the historical setting of the University of Leuven in Belgium. The series of international conferences on thinking, of which the meeting in Leuven was part, has been primarily concerned with deductive inference, problem solving, and decision making. Our symposium was intended to raise

the profile, in Europe particularly, of work on induction. Many, but not all, of the chapter authors for this book talked at the symposium, which took place on Saturday 24 July. Doug Medin, Pat Shafto, Paul Thagard, Brett Hayes, Josh Tenenbaum, Evan Heit, and Aidan Feeney all talked about their work on induction, and Steven Sloman was the discussant. John Coley, Mike Oaksford, and Bob Rehder were also present and contributed greatly on the day, and Lance Rips had also been vesting Leuven. The symposium went so well that we decided to press on with plans for a book. But what kind of book should it be?

The last book devoted wholly to the psychology of induction was Holland, Holyoak, Nisbett, and Thagard's landmark book on induction, which appeared in 1986. Broadly speaking, Holland and colleagues' book attempted to apply just one general explanatory framework to a variety of inductive phenomena including analogy, scientific discovery, generalisation, and rule learning. Since 1986 the field has changed and developed enormously. There have been great accomplishments in the study of how inductive reasoning develops, as well as a focus on precise mathematical modelling of induction throughout the 1990s, culminating in very powerful Bayesian models of inductive thinking that have emerged over the last few years. Other developments include a recent focus on the relationship between induction and deduction, widespread consideration of the role of categories and background knowledge in induction, and significant progress on questions about individual and cultural differences in inductive generalisation.

To emphasise how the field has changed since the mid-1980s, and because of the range of work on induction that has emerged in the intervening time, this book reverses the tactic employed by Holland and colleagues; instead of applying one approach to a variety of inductive phenomena, for the most part this book will focus on how a wide range of methodological and modelling approaches have increased our understanding of induction.

There is often a concern that edited books can lack coherence. Given that we wished to collect contributions on a wide range of approaches, this could have been a problem here. However, as most chapter authors presented at, or attended, the symposium in Leuven, we were all aware while writing our chapters of the concerns of other chapter authors. In addition, every chapter was read by two other chapter authors and every chapter was redrafted in the light of other authors' comments. Our goal throughout has been to achieve integration and overlap between chapters, and we hope that we have achieved coherence.

WHO IS THIS BOOK FOR?

This book is intended to be read by anyone interested in thinking. Our goal was to capture the current state of the art in our field. Thus all readers – be they psychologists, mathematical modellers, cognitive scientists, or philosophers – with even a passing interest in induction should find something to hold their attention here. Although we think that postgraduate students might be interested in most chapters, we also hope that undergraduates will find useful material. Whilst some of the chapters in this book focus in great detail on a very specific issue, others give very accessible overviews of big swathes of the literature. Although editors should probably refrain from favouring some contributions over others, because we think that all of the chapters in this book are excellent, we are happy to particularly recommend Chapters 1, 8, and 9 to undergraduates exploring the psychology of induction for the first time.

We also hope that many of our colleagues researching other forms of thinking such as deduction, decision making, analogy, and problem solving will be interested in this book. Whereas some of the issues, particularly those concerning development, culture, and individual differences, are likely to be similar across many forms of thinking, others are not. The particular issue that is distinctive to induction is that of knowledge; induction involves reasoning from all relevant belief. Whereas in some forms of reasoning it is an error to consider one's own beliefs, for inductive reasoning it is a necessity. Accordingly, to explain induction one has to consider how knowledge is structured, which type of knowledge is most relevant when, and how that knowledge is brought to bear on the premises of inductive arguments. Although these are not issues the literature on deduction, for example, has always highlighted, nevertheless we think that consideration of the role of different types of knowledge in reasoning might be very beneficial for researchers interested in deduction.

Finally, we think that Holland and colleagues were correct in suggesting that questions to do with induction are central to the study of cognitive science. How agents reuse previous experience stored in the form of knowledge is a key question for anyone interested in cognition. The diverse perspectives offered in this book should therefore be of interest to a wide range of researchers. Furthermore, we have tried very hard in this book to ensure coverage of molehills and mountains: molehills for the specialists and mountains for the general cognitive science reader.

ORGANISATION OF THE BOOK

When we drew up our list of invitees, the most important consideration was that we include a coherent set of contributions reflecting a range of approaches and methods important in contemporary cognitive science. These approaches are summarised in Chapter 1 by Evan Heit. Following a discussion of the differences between induction and deduction, the chapter uses the phenomenon of evidential diversity to explore approaches from philosophy, experimental psychology, mathematical modelling, and developmental science. After these introductory chapters, the book contains a further four sections, which we will briefly summarise.

The centrality of induction to cognitive development, and the centrality of the developmental approach to research on induction, can be seen in the chapters by Hayes and by Medin and Waxman. In Chapter 2 Brett Hayes provides a comprehensive overview of our current understanding of how inductive reasoning develops. He discusses the information that children use for inductive reasoning and presents the development of induction as being about the development of knowledge. Hayes also describes the uses to which developmental data may be put when evaluating theories of induction. Chapter 3, written by Doug Medin and Sandra Waxman, nicely illustrates how developmental data can constrain theory. Medin and Waxman concern themselves with asymmetries (preferences for arguments from certain categories over arguments from other categories) in children's reasoning. In contrast to Chapters 1 and 2, the chapter by Medin and Waxman is tightly focused on a single issue. However, by considering a range of possible explanations for asymmetries in the light of novel developmental evidence, some of which is cross-cultural, the authors are able to come down in favour of one account over all others.

The next three chapters all concern knowledge and induction. In Chapter 4, Bob Rehder makes a strong case for the importance of causal knowledge in induction. This chapter describes evidence that causal knowledge about a to-be-projected property affects its projectability, and it discusses the relationship between knowledge about similarity or taxonomic relations and knowledge about causal relations. Whereas the chapter by Rehder considers cases in which the two forms of knowledge are in competition, Chapter 5, contributed by Pat Shafto, John Coley, and Anna Vitkin, considers the role of availability in determining whether taxonomic or ecological knowledge dominates in induction. Shafto and colleagues consider two factors that might affect which type of knowledge is, or becomes, most available: context and experience. This framework proves a neat way of organising recent findings concerning

the effects of content, property, expertise, and culture on inductive reasoning. Together these chapters demonstrate how far the field has moved beyond original attempts to model inductive inference using notions such as typicality and similarity.

Of course, similarity remains an extremely important construct in the literature on induction, and many inductive inferences will be based on similarity. One of the problems for models that have exploited similarity as an explanatory mechanism is the property that people are asked to project from members of one category to another. Typically, these models do not take account of the meaning of properties. In Chapter 6, Blok, Osherson, and Medin describe and experimentally verify a mathematical model of induction that takes as input (a) the similarity between the categories in the argument and (b) premise and conclusion probabilities. As the nature of the property determines the probability of the statements in an argument, this model can capture results for meaningful properties. Thus, it places similarity-based accounts on stronger footing.

The chapter by Blok and colleagues comes out of the very rich tradition of mathematical modelling in the literature on induction. So too does Chapter 7 on Bayesian models by Josh Tenenbaum, Charles Kemp, and Pat Shafto. The main contribution of this chapter is to show how certain assumptions about how knowledge is represented allow us to generate priors for a Bayesian belief-updating process. Thus, inductive reasoning can be given a comprehensive Bayesian treatment, which captures many of the knowledge effects discussed in previous chapters.

Chapter 8, by Greg Murphy and Brian Ross, offers an interesting perspective on Bayesian approaches to inductive reasoning. When generating a rating of argument strength, the models described by Tenenbaum and colleagues work through all of the hypotheses that are consistent with a particular inductive argument. Murphy and Ross show that, in many situations, people tend not to consider alternative hypotheses when evaluating inductive arguments. Murphy and Ross's chapter is problematic for the Bayesian view and asks questions about the link between normative and psychological models (as do Steven Sloman's comments in his integrative chapter), which researchers interested in Bayes would do well to address.

The volume closes with a set of chapters concerned with relations between induction and other forms of thinking. Paul Thagard outlines a theory of abductive reasoning, a form of induction in which one reasons to an explanation. This chapter touches on several themes in contemporary cognitive science as it posits an important role for the emotions and attempts to give a neuropsychologically plausible account of cognitive processes. Thagard was

one of the authors of the 1986 book on induction, and his chapter brings an especially broad perspective to the study of thinking. As is apparent from this chapter, there are many types of thinking, and Thagard's comments on the likely frequency of deductive and inductive inference in everyday life are sobering.

Chapter 10, by Lance Rips and Jennifer Asmuth, although explicitly about a rarefied form of reasoning in mathematics, is ultimately concerned with the relationship between deduction and induction. Previous work (Rips, 2001) suggests that inductive and deductive reasoning are dissociated. Rips and Asmuth consider the case of mathematical induction, which they view as a form of deductive thinking. Interestingly, even quite advanced students of mathematics have problems with this form of reasoning.

Mike Oaksford and Ulrike Hahn in Chapter 11 argue for a probabilistic approach to argument evaluation. They claim that induction and deduction may be treated as belief-updating problems, although they do not rule out the possibility that some small amount of deduction takes place in the world. Because of its Bayesian character, this chapter is complementary to the chapter by Tenenbaum and colleagues. Also notable in this chapter is an attempt to get to grips with, from a Bayesian point of view, well-known informal reasoning fallacies, such as the argument from ignorance. Oaksford and Hahn demonstrate that some of these so-called fallacies may be justified from a Bayesian point of view.

In Chapter 12, Feeney takes a different perspective on the relationship between induction and other forms of thinking. Whereas Rips and Asmuth suggest that induction and deduction are different types of thinking, and Oaksford and Hahn suggest that, generally speaking, there is only one type of thinking, Feeney makes the argument that induction is no different from deduction in that both generally require the operation of two different types of thinking process. One of these is fast and associative whilst the other is slow and symbol manipulating (see Evans & Over, 1996; Sloman, 1996). The dual-process argument is not new, but its application here leads to a novel conception of inductive reasoning that is often thought of as involving only associative processes. Interestingly, however, causal knowledge is somewhat problematic for this dual-process view.

Finally, in Chapter 13, Steven Sloman comments on the other chapters in the book and draws together their common themes and implications in an interesting and provocative way. We do not want to spoil his punchlines here, but he has many interesting things to say about the relationship between types of thinking and about Bayesian approaches to induction. In many ways, this is the most important chapter in this book, as its role is to explicitly comment

on the state of the field rather than merely describing and interpreting what is to be found in the literature.

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Editors
Aidan Feeney
Durham University
Evan Heit
University of California, Merced