The Cambridge Handbook of Expertise and Expert Performance

Second Edition

In this updated and expanded edition of The Cambridge Handbook of Expertise and Expert Performance, some of the world’s foremost experts on expertise share their scientific knowledge of expertise and expert performance and show how experts may differ from non-experts in terms of development, training, reasoning, knowledge, and social support. The book reviews innovative methods for measuring experts’ knowledge and performance in relevant tasks. Sixteen major domains of expertise are covered, including sports, music, medicine, business, writing, and drawing, with leading researchers summarizing their knowledge about the structure and acquisition of expert skills and knowledge, and discussing future prospects. General issues that cut across most domains are reviewed in chapters on various aspects of expertise, such as general and practical intelligence, differences in brain activity, self-regulated learning, deliberate practice, aging, knowledge management, and creativity.

K. Anders Ericsson is currently the Conradi Eminent Scholar and Professor of Psychology at Florida State University. He is also a Fellow of the Center for Advanced Study in the Behavioral Sciences, the American Psychological Association, the Association for Psychological Science, and a member of the Royal Swedish Academy of Engineering Sciences. His research has been featured in cover stories in Scientific American, Time, Fortune, the Wall Street Journal, and the New York Times. He has been invited to give keynote presentations at conferences of surgeons, musicians, teachers, clinical psychologists, athletes, and coaches as well as professional sports organizations, such as the Philadelphia Eagles, the San Antonio Spurs, the Toronto Blue Jays, and Manchester City Football Club.

Robert R. Hoffman is a recognized world leader in cognitive systems engineering and human-centered computing. Currently he is senior research scientist at the Institute for Human and Machine Cognition in Pensacola, FL. He is a fellow of the Association for Psychological Science, fellow of the Human Factors and Ergonomics Society, senior member of the Association for the Advancement of Artificial Intelligence, and a Fulbright scholar. His PhD is in experimental psychology from the University of Cincinnati. His Postdoctoral Associateship was at the Center for Research on Human Learning at the University of Minnesota. He also served on the faculty of the Institute for Advanced Psychological Studies at Adelphi University. Hoffman has been recognized internationally in psychology, remote sensing, human factors engineering, intelligence analysis, weather forecasting, and artificial intelligence – for his research on the psychology of expertise, the
methodology of cognitive task analysis, HCC issues for intelligent systems technology, and the design of macrocognitive work systems.

Aaron Kozbelt is Professor of Psychology at Brooklyn College and the Graduate Center of the City University of New York. His research focuses on creativity and cognition in the fine arts, with an emphasis on perception in visual artists, lifespan creativity in composers, and evolutionary aspects of aesthetics and creativity. He has published more than 80 peer-reviewed articles and book chapters, and his research has been funded by the National Science Foundation. He serves on several editorial boards and has received several national and international awards for his research, including the Daniel Berlyne Award from Division 10 of the American Psychological Association and the Alexander Gottlieb Baumgarten Award from the International Association of Empirical Aesthetics.

A. Mark Williams is Professor and Chair of the Department of Health, Kinesiology, and Recreation at the University of Utah. He is a fellow of the British Psychological Society, the British Association of Sport and Exercise Science, the National Academy of Kinesiology, and the European College of Sports Science. His research interests focus on the neural and psychological mechanisms underpinning the acquisition and development of perceptual-cognitive and perceptual-motor skills. He has published over 300 journal articles and book chapters, and has written or edited 15 books. He is Editor-in-Chief for the Journal of Sports Science and sits on the editorial boards of several prominent journals. His research has been funded by research councils in Australia and the UK, by industrial partners such as Nike, and by several professional sports teams and national and international governing bodies.
The Cambridge Handbook of Expertise and Expert Performance

Second Edition

Edited by

K. Anders Ericsson
Florida State University

Robert R. Hoffman
Institute for Human and Machine Cognition

Aaron Kozbelt
Brooklyn College, City University of New York

A. Mark Williams
University of Utah
## Contents

*Notes on Contributors*  
*Acknowledgments*  

### Part I Introduction and Perspectives

   K. Anders Ericsson  
   page 3

2. A Sociological/Philosophical Perspective on Expertise: The Acquisition of Expertise through Socialization  
   Harry Collins and Robert Evans  
   page 21

3. Reframing Expertise and its Development: A Lifeworld Perspective  
   Gloria Dall’Alba  
   page 33

4. The Evolution of Expertise  
   Bo Winegard, Benjamin Winegard, and David C. Geary  
   page 40

5. Expertise in Other Animals: Canines as an Example  
   William S. Helton and Nicole D. Helton  
   page 49

### Part II Overview of Approaches to the Study of Expertise: Brief Historical Accounts of Theories and Methods

6. Studies of Expertise from Psychological Perspectives: Historical Foundations and Recurrent Themes  
   Paul J. Feltovich, Michael J. Prietula, and K. Anders Ericsson  
   page 59

7. Expert Systems: A Perspective from Computer Science  
   Bruce G. Buchanan, Randall Davis, Reid G. Smith, and Edward A. Feigenbaum  
   page 84

8. Developing Occupational Expertise through Everyday Work Activities and Interactions  
   Stephen Billett, Christian Harteis, and Hans Gruber  
   page 105

   Harald A. Mieg and Julia Evetts  
   page 127
Part III Methods for Studying the Structure of Expertise

10 Perception in Expertise
DANIEL LANDY

11 Eliciting and Representing the Knowledge of Experts
GAVAN LINTERN, BRIAN MOON, GARY KLEIN, AND ROBERT R. HOFFMAN

12 Capturing Expert Thought with Protocol Analysis: Concurrent Verbalizations of Thinking during Experts' Performance on Representative Tasks
K. ANDERS ERICSSON

13 Methods for Studying the Structure of Expertise: Psychometric Approaches
PHILIP L. ACKERMAN AND MARGARET E. BEIER

14 Studies of the Activation and Structural Changes of the Brain Associated with Expertise
MERIM BILALIĆ AND GUILLERMO CAMPITELLI

Part IV Methods for Studying the Acquisition and Maintenance of Expertise

15 Collecting and Assessing Practice Activity Data: Concurrent, Retrospective, and Longitudinal Approaches
JOSEPH BAKER, NICOLA J. HODGES, AND MELISSA J. WILSON

16 Multidisciplinary Longitudinal Studies: A Perspective from the Field of Sports
MARIJE T. ERFERINK-GEMSER, SANNE C. M. TE WIERIKE, AND CHRIS VISSCHER

17 Using Cases to Understand Expert Performance: Method and Methodological Triangulation
MICHAEL D. MUMFORD, TRISTAN MCINTOSH, AND TYLER MULHEARN

18 Historiometric Methods
DEAN KEITH SIMONTON

Part V.I Domains of Expertise: Professions

19 Expertise in Medicine and Surgery
GEOFFREY R. NORMAN, LAWRENCE E. M. GRIERSON, JONATHAN SHERBINO, STANLEY J. HAMSTRA, HENK G. SCHMIDT, AND SILVIA MAMEDE

20 Expertise and Transportation
FRANCIS T. DURSO, ANDREW R. DATTEL, AND VLAD L. POP
## Contents

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>Expertise in Professional Design</td>
<td>372</td>
</tr>
<tr>
<td>22</td>
<td>Toward Deliberate Practice in the Development of Entrepreneurial Expertise: The Anatomy of the Effectual Ask</td>
<td>389</td>
</tr>
<tr>
<td>23</td>
<td>Professional Writing Expertise</td>
<td>413</td>
</tr>
<tr>
<td>24</td>
<td>Expertise and Expert Performance in Teaching</td>
<td>431</td>
</tr>
<tr>
<td>25</td>
<td>Expert Professional Judgments and “Naturalistic Decision Making”</td>
<td>453</td>
</tr>
<tr>
<td>26</td>
<td>Skilled Decision Theory: From Intelligence to Numeracy and Expertise</td>
<td>476</td>
</tr>
<tr>
<td>27</td>
<td>What Makes an Expert Team? A Decade of Research</td>
<td>506</td>
</tr>
</tbody>
</table>

### Part V.II Domains of Expertise: Arts, Sports, Games, and Other Skills

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td>Expertise in Music</td>
<td>535</td>
</tr>
<tr>
<td>29</td>
<td>Brain Changes Associated with Acquisition of Musical Expertise</td>
<td>550</td>
</tr>
<tr>
<td>30</td>
<td>Expertise in Drawing</td>
<td>576</td>
</tr>
<tr>
<td>31</td>
<td>Expertise in Chess</td>
<td>597</td>
</tr>
<tr>
<td>32</td>
<td>Mathematical Expertise</td>
<td>616</td>
</tr>
<tr>
<td>33</td>
<td>Expertise in Second Language Vocabulary</td>
<td>634</td>
</tr>
<tr>
<td>34</td>
<td>Expertise in Sport: Specificity, Plasticity, and Adaptability in High-Performance Athletes</td>
<td>653</td>
</tr>
</tbody>
</table>
Part VI  Generalizable Mechanisms Mediating Types of Expertise

35 Superior Anticipation  677
Bruce Abernethy, Damian Farrow, and David L. Mann

36 Superior Working Memory in Experts  696
K. Anders Ericsson

37 Expertise and Situation Awareness  714
Mica R. Endsley

Part VII  General Issues and Theoretical Frameworks

38 The Differential Influence of Experience, Practice, and Deliberate Practice on the Development of Superior Individual Performance of Experts  745
K. Anders Ericsson

39 Practical Intelligence and Tacit Knowledge: An Ecological View of Expertise  770
Anna T. Cianciolo and Robert J. Sternberg

40 Cognitive Load and Expertise Reversal  793
Slava Kalyuga and John Sweller

41 Expertise and Structured Imagination in Creative Thinking: Reconsideration of an Old Question  812
Robert W. Weisberg

42 Aging and Expertise  835
Ralf T. Krampe and Neil Charness

Index of Subjects  857
Notes on Contributors

BRUCE ABERNEThY, School of Human Movement & Nutrition Sciences, The University of Queensland, Australia

PHILIP L. ACKERMAN, School of Psychology, Georgia Institute of Technology, Georgia

JINAN N. ALLAN, National Institute for Risk & Resilience, and Department of Psychology, University of Oklahoma, Oklahoma

ECKART ALTENMÜLLER, Institute of Music Physiology and Musicians’ Medicine, University of Music, Drama and Media, Hanover, Germany

JOSEPH BAKER, School of Kinesiology and Health Science, York University, Canada

MARGARET E. BEIER, Department of Psychology, Rice University, Texas

MERIM BILALIĆ, Department of Psychology, University of Northumbria at Newcastle, UK

STEPHEN BILLET, School of Education and Professional Studies, Griffith University, Australia

BRUCE G. BUCHANAN, Computer Science Department, University of Pittsburgh, Pennsylvania

BRIAN BUTTERWORTH, Institute of Cognitive Neuroscience, University College London, UK

GUILLERMO CAMPITELLI, School of Arts and Humanities, Edith Cowan University, Australia

NEIL CHARNESS, Department of Psychology, Florida State University, Florida

ANNA T. CIANCIOLINO, School of Medicine, Southern Illinois University, Illinois

EDWARD T. COKELEY, National Institute for Risk & Resilience, and Department of Psychology, University of Oklahoma, Oklahoma, and Max Planck Institute for Human Development, Germany

HARRY COLLINS, School of Social Sciences, Cardiff University, UK

NIGEL CROSS, Faculty of Science, Technology, Engineering & Mathematics, The Open University, UK

GLORIA DALL’ALBA, School of Education, The University of Queensland, Australia
Notes on Contributors

Andrew R. Dattel, College of Aviation, Embry-Riddle Aeronautical University, Florida

Randall Davis, Computer Science and Artificial Intelligence Laboratory, Massachusetts Institute of Technology, Massachusetts

Nicholas Dew, Graduate School of Business and Public Policy, Naval Postgraduate School, California

Francis T. Durso, School of Psychology, Georgia Institute of Technology, Georgia

Marije T. Elferink-Gemser, Center for Human Movement Sciences, University Medical Center Groningen, University of Groningen, The Netherlands

Mica R. Endsley, SA Technologies, Inc., Arizona

K. Anders Ericsson, Department of Psychology, Florida State University, Florida

Robert Evans, School of Social Sciences, Cardiff University, UK

Julia Evetts, School of Sociology and Social Policy, University of Nottingham, UK

Damian Farrow, Institute for Sport, Exercise and Active Living, Victoria University, Australia

Edward A. Feigenbaum, Computer Science Department, Stanford University, California

Paul J. Feltovich, Institute for Human and Machine Cognition, Florida

Adam Feitz, Department of Cognitive and Learning Sciences, Michigan Technological University, Michigan

Ute Fischer, School of Literature, Media & Communication, Georgia Institute of Technology, Georgia

Paul R. Ford, Centre for Sport and Exercise Science and Medicine, University of Brighton, UK

Shinichi Furuya, SONY Computer Science Laboratory, Tokyo, Japan

Rocio Garcia-Retamero, Department of Experimental Psychology, University of Granada, Spain, and Max Planck Institute for Human Development, Germany

Melodie Garnier, University of Cambridge, UK

David C. Geary, Department of Psychological Sciences, University of Missouri, Missouri

Saima Ghazal, Institute of Applied Psychology, University of the Punjab, Pakistan

Fernand Gobet, Department of Psychological Sciences, University of Liverpool, UK
Notes on Contributors

LAWRENCE E. M. GRIERSON, Department of Family Medicine, McMaster University, Canada

HANS GRUBER, Department of Educational Science, University of Regensburg, Germany, and Faculty of Education, University of Turku, Finland

STANLEY J. HAMSTRA, Accreditation Council for Graduate Medical Education, Illinois

CHRISTIAN HARTEIS, Institute of Educational Science, University of Paderborn, Germany

NICOLE D. HELTON, Independent scholar, Virginia

WILLIAM S. HELTON, Department of Psychology, George Mason University, Virginia

NICOLA J. HODGES, School of Kinesiology, University of British Columbia, Canada

ROBERT R. HOFFMAN, Institute for Human and Machine Cognition, Florida

SLAVA KALYUGA, School of Education, University of New South Wales, Australia

RONALD T. KELLOGG, Department of Psychology, St. Louis University, Missouri

GARY KLEIN, MacroCognition LLC, District of Columbia

REINHARD KOPIEZ, Hochschule für Musik, Theater und Medien, Germany

AARON KOZBELT, Department of Psychology, Brooklyn College of the City University of New York, New York

RALF T. KRAMPE, Brain & Cognition Laboratory, University of Leuven, Belgium

CHRISTINA LACERENZA, Leeds School of Business, University of Colorado, Boulder, Colorado

DAVID LANDY, Department of Psychological and Brain Sciences, Indiana University, Indiana

ANDREAS C. LEHMANN, Hochschule für Musik Würzburg, Germany

GAVAN LINTERN, Accident Research Centre, Monash University, Australia

MARIJANA MACIS, Manchester Metropolitan University, UK

SILVIA MAMEDE, Graduate School of Social Sciences and the Humanities, Erasmus University, Rotterdam, The Netherlands

DAVID L. MANN, Department of Human Movement Sciences, Vrije Universiteit Amsterdam, The Netherlands

SHANNON MARLOW, Department of Psychology, Rice University, Texas

TRISTAN MCINTOSH, Department of Psychology, University of Oklahoma, Oklahoma

HARALD A. MIEG, Geography Department, Humboldt-Universität zu Berlin, Germany
Notes on Contributors

KEVIN F. MILLER, School of Education, University of Michigan, Michigan
BRIAN MOON, Perigean Technologies LLC, Virginia
KATHLEEN MOSIER, Department of Psychology, San Francisco State University, California
TYLER MULHEARN, Department of Psychology, University of Oklahoma, Oklahoma
MICHAEL D. MUMFORD, Center for Applied Social Research, and Department of Psychology, University of Oklahoma, Oklahoma
GEOFFREY R. NORMAN, Department of Health Research Methods, McMaster University, Canada
JUSTIN OSTROFSKY, School of Social and Behavioral Sciences, Stockton University, New Jersey
DAFINA PETROVA, Department of Experimental Psychology, University of Granada, Spain
VLAD L. POP, Georgia Tech Research Institute, Georgia
MICHAEL J. PRIETULA, Goizueta Business School, Emory University, Georgia
ANUSHA RAMESH, Darden School of Business Administration, University of Virginia, Virginia
STUART READ, Atkinson Graduate School of Management, Willamette University, Oregon
EDUARDO SALAS, Department of Psychology, Rice University, Texas
SARAS D. SARASVATHY, Darden Graduate School of Business Administration, University of Virginia, Virginia
HENK G. SCHMIDT, Department of Psychology, Erasmus University, Rotterdam, The Netherlands
NORBERT SCHMITT, School of English, University of Nottingham, UK
JONATHAN SHERBINO, Hamilton General Hospital, McMaster University, Canada
DEAN KEITH SIMONTON, Department of Psychology, University of California at Davis, California
REID G. SMITH, i2k Connect LLC, Texas
SHIRLEY C. SONESH, Sonnenschein Consulting LLC, Louisiana
ROBERT J. STEINBERG, College of Human Ecology, Cornell University, New York
JAMES W. STIGLER, Department of Psychology, University of California at Los Angeles, California
JOHN SWELLER, School of Education, University of New South Wales, Australia
SANNE C. M. TE WIERIKE, Sport Science Institute Groningen, The Netherlands
LAURA VILKAÎTĖ, Faculty of Philology, Vilnius University, Lithuania
CHRIS VISSCHER, Center for Human Movement Sciences, University Medical Center Groningen, University of Groningen, The Netherlands
PAUL WARD, School of Psychological Sciences, University of Northern Colorado, Colorado
ROBERT W. WEISBERG, Department of Psychology, Temple University, Pennsylvania
A. MARK WILLIAMS, Department of Health, Kinesiology, and Recreation, University of Utah, Utah
MELISSA J. WILSON, Paralympics New Zealand, New Zealand
BENJAMIN WINEGARD, Carroll College, Montana
BO WINEGARD, Department of Psychology, Florida State University, Florida
Acknowledgments

K. Anders Ericsson wants to gratefully acknowledge the financial support provided by the Conradi Eminent Scholar Endowment at the Florida State Foundation during the editing phase of the work on this new edition of the handbook.

Robert R. Hoffman would like to thank the Institute for Human and Machine Cognition for its support during the writing and editing process.

Aaron Kozbelt would like to acknowledge Brooklyn College of the City University of New York for support during the preparation of the handbook.

A. Mark Williams would like to thank the College of Health at the University of Utah for its support during the writing and editing process.