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THE SCIENCE OF EXPERTISE

Behavioral, Neural, and Genetic Approaches to Complex Skill

Edited by David Z. Hambrick, Guillermo Campitelli, and Brooke N. Macnamara

With a foreword by Robert Plomin

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1

INTRODUCTION

A Brief History of the Science of Expertise and Overview of the Book

David Z. Hambrick, Guillermo Campitelli, and
Brooke N. Macnamara

The Science of Expertise: A Brief History

Nearly everyone has witnessed a display of complex skill that is so extraordina
so far outside the normal range of human capabilities—that it defies belief.
1968 Olympics in Mexico City were witness to arguably the greatest ath
feat of all time, when Bob Beamon won the gold medal in the long jump
a leap of 29 feet 2¼ inches. In an event usually won by a few inches, Bea
bettered silver medalist Klaus Beer by a bewildering 28 inches. Nearly a
century later, his Olympic record still stands. More recently, the world wat
as 60-year old Diana Nyad swam the 110 miles between Havana, Cuba,
Key West, Florida. Performances of prodigies are especially memorable for
seeming otherworldliness, as when the pianist Evgeny Kissin made his d
with the Moscow Philharmonic Orchestra at the age of 12, and when 13-y
old Magnus Carlsen famously played chess World No. 1 Garry Kasparov
draw. We also admire extraordinary skill in everyday life—the master mech
for uncanny ability to diagnose and fix what ails our automobiles, the surg
for acumen in removing disease with surgical instruments without harmin
patient, the potter who transforms lumps of clay into elegant bowls, the
who deftly lands a jumbo jet in bad weather, and so on.

What is the origin of individual differences in expertise? This is a ce
question for the science of expertise, and the major focus of this book. G
that individual differences in skill are so obvious through casual observatio
may also be one of humankind's earliest existential questions. Consider th
prehistoric art we see what may well have been celebration of exceptional
formance: Paintings up to 20,000 years old in the Lascaux cave in France inc
images of wrestlers and sprinters, and in the Cave of Swimmers in present
Egypt, depictions of archers and swimmers date to 6000 B.C.E. Several thou

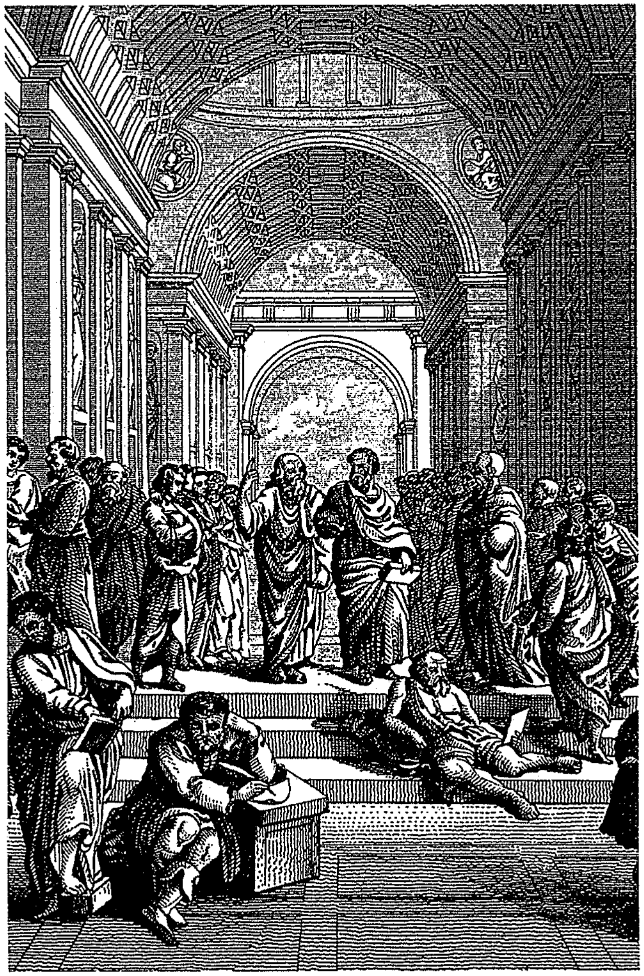

FIGURE 1.1 Raphael. The School of Athens. Detail from 1873 illustration of the fresco (1510–1512), which is in the Vatican. Image credit: bauhaus1000.

years later, the Ancient Greeks laid the foundation for the contemporary debate over the origins of expertise. In *The Republic* (ca. 380 B.C.E.), Plato made the innatist argument that "no two persons are born alike but each differs from the other in individual endowments." Aristotle, Plato's student who is often regarded as the "first empiricist," countered that experience is the ultimate source of knowledge. These differing philosophies are symbolized in the fresco *School of Athens* (1509–1511) by the Italian Renaissance artist Raphael (Figure 1.1). Plato and Aristotle are pictured in the center of the fresco; each holds a book in his left hand and gestures with his right—Plato upward to the heavens and Aristotle outward to the concrete world.

What might be considered the first scientific study of expertise was p
lished in 1835 by the Ghent-born statistician and sociologist Adolphe Quet
(see Simonton, 2016), who introduced the normal curve to describe indivi
differences. Using archival data, Quetelet documented that output in fam
French and English dramatists peaked at about age 50. Some 35 years la
making use of Quetelet's statistical work, Francis Galton (1869) publis
his groundbreaking volume *Hereditary Genius*. Galton's major question
whether intellectual ability is heritable in the same way that his half-co
Charles Darwin had argued that physical characteristics of creatures such as
size and length of birds' beaks are heritable. There were no standardized test
intelligence in the mid-1800s, so Galton scoured *Who's Who*-type biograph
dictionaries and used reputation as a proxy for ability. Galton discovered t
within a given field, eminent individuals tended to be biologically related m
than would be expected by chance. For example, he noted that there w
more than 20 eminent musicians in the Bach family—Johann Sebastian be
just the most famous—and he observed that the Bernoulli family "comprise
extraordinary number of eminent mathematicians and men of science." Gal
concluded that genius arises almost inevitably from "natural ability."

Galton's (1869) book created a stir. The Swiss botanist Alphonse Pyrame
Candolle (1873) conducted his own biographical study and found that sc
countries produced more scientists than others, taking population into acco
For example, his native Switzerland produced over 10 percent of the scien
in his sample, but accounted for less than 1 percent of the European populati
De Candolle concluded that environmental factors—or what he called "ca
favorables"—were the primary antecedents of eminence (Fancher, 1983).
a similar vein, Edward Thorndike (1912), the father of educational psych
ogy, claimed that "when one sets oneself zealously to improve any ability,
amount gained is astonishing" and added that "we stay far below our own p
sibilities in almost everything we do . . . not because proper practice would
improve us further, but because we do not take the training or because we t
it with too little zeal" (p. 108). John Watson (1930) added that "practicing m
intensively than others . . . is probably the most reasonable explanation we h
today not only for success in any line, but even for genius" (p. 212).

Thus, from antiquity on, the pendulum has swung between the view t
experts are "born" and the view that they are "made." In psychology,
experts-are-made view has dominated the scientific study of expertise for
better part of 50 years. Building on earlier work by de Groot (1946/197
Chase and Simon (1973) had participants representing three levels of chess s
(novice, intermediate, and master) view and attempt to recreate arrangement
chess positions that were either plausible game positions or random. The ma
finding was that chess skill facilitated recall of the game positions, but not
random positions. Thus, Chase and Simon concluded that the primary fac
underlying chess skill is not superior short-term memory capacity, but a la

"vocabulary" of game positions. More generally, they argued that although "there clearly must be a set of specific aptitudes . . . that together comprise a talent for chess, individual differences in such aptitudes are largely overshadowed by immense differences in chess experience. Hence, the overriding factor in chess skill is practice" (Chase & Simon, 1973, p. 279).

Subsequent research showed just how powerful the effects of training on performance can be. As a particularly striking example, Ericsson, Chase, and Faloon (1980) reported a case study of a college student (S.F.), who through more than 230 hours of practice, increased the number of random digits he could recall from a typical 7 to a world record 79 digits. (Today, the world record for random digit memorization is an astounding 456 digits.) Verbal reports revealed that S.F., a collegiate track runner, accomplished this feat by recoding sequences of digits as running times, ages, or dates, and encoding the groupings into long-term memory *retrieval structures*. For example, he remembered 3596 as "3 minutes, 59.6 seconds, fast 1-mile time." Ericsson *et al.* concluded that there is "seemingly no limit to improvement in memory skill with practice" (1980, p. 1182).

The consensus that emerged from all this research was that expertise reflects acquired characteristics (nurture), with essentially no important role for genetic factors (nature). This environmentalist view reached its apogee in the early 1990s, with publication of Ericsson, Krampe, and Tesch-Römer's (1993) seminal article on "deliberate practice." In a pair of studies, Ericsson *et al.* found positive correlations between estimated amount of deliberate practice (practice alone) and skill level in music. The most skilled musicians had accumulated thousands of hours more deliberate practice than their less accomplished counterparts. In the spirit of Watson (1930), Ericsson *et al.* concluded that "high levels of deliberate practice are necessary to attain expert level performance" (Ericsson *et al.*, p. 392) and explained that their "account does not depend on scarcity of innate ability (talent)" (Ericsson *et al.*, p. 392). Another important event was the publication of the field's first handbook—the 900-page *Cambridge Handbook on Expertise and Expert Performance* (Ericsson, Charness, Feltovich, & Hoffman, 2006). Though this volume was a valuable resource for the field, it seems fair to say that the focus was overwhelmingly on experiential determinants of expertise (i.e. practice/training). There are, for example, 102 index entries for "deliberate practice" and "training," compared to 12 for "talent" and "genetics."

There was, however, growing dissent in the literature. Simonton (1999), one of the most eloquent commentators, acknowledged that "it is extremely likely that environmental factors, including deliberate practice, account for far more variance in performance than does innate capacity in every salient talent domain" (p. 454), but continued: "Even so, psychology must endeavor to identify all of the significant causal factors behind exceptional performance rather than merely rest content with whatever factor happens to account for the most variance" (p. 454). In a similar vein, Gagné (1999) argued that there is "[n]o doubt that the single most important source of individual differences in the case of SYSDEV [systematically developed] abilities is the amount of LTP [lear training, and practice]. But . . . genetic endowment is also a significant, a indirect, cause of individual differences in these abilities."

Dissent grew into empirical challenge in the mid-2000s—which, coinci tally or not, was around the time the environmentalist view was populariz books such as Malcolm Gladwell's (2008) bestseller *Outliers: The Story of S* and Geoff Colvin's (2010) *Talent is Overrated: What Really Separates World-* *Performers from Everybody Else*. In one of the first direct tests of the delib practice view, Gobet and Campitelli (2007) found that there was massive ability in the amount of deliberate practice required for chess players to r "master" status—from about 3,000 hours to over 23,000 hours. The implica of this finding was that factors other than deliberate practice must also pla important role in becoming highly skilled in chess.

Subsequently, the three of us (with numerous colleagues around the w published a series of papers demonstrating that deliberate practice is an impo piece of the expertise puzzle, just not the only important piece. As one exan Meinz and Hambrick (2010) found that *working memory capacity*, which is kn to be substantially heritable, added to the prediction of individual differe in piano sight-reading skill, above and beyond deliberate practice. (To be sur terms of variance explained, the effect of deliberate practice was larger than effect of working memory capacity—45 percent vs. 7 percent. However, latter effect size is not trivial from either a statistical or theoretical perspectiv few years later, a special issue of the journal *Intelligence* brought together a co tion of articles on the acquisition of expertise—nearly all of which challenged environmentalist stance on expertise. We and our colleagues (Hambrick *e* 2014) reported that deliberate practice accounted for no more than about a t of the variance in expertise in chess and music, leaving the rest unexpla and potentially explainable by other factors. Plomin and colleagues sho that genetic factors accounted for over half of the variance between expert non-expert readers (Plomin, Shakeshaft, McMillan, & Trzaskowski, 2014), Ruthsatz and colleagues (Ruthsatz, Ruthsatz-Stephens, & Ruthsatz, 2014) s marized evidence showing that prodigies are extremely high in working mem

What all this evidence indicated to us is that expertise can never be adequ understood by focusing on only environmental factors (or, of course, only ge factors). Rather, what is needed to advance scientific understanding of expe are *multifactorial models* that take into account *all* relevant factors. Figure displays a general framework for thinking about expertise from this perspec (theoretical models presented later in the book give more specific guidar There are seven major categories of predictor constructs: (1) *developmental fa* including age and starting age; (2) *background factors*, such as socioeconomic st country of origin, and parental involvement; (3) *ability factors*, including b cognitive, perceptual, and physiological traits; (4) *non-ability factors*, such as sonality, motivation, and temperament; (5) *domain-specific knowledge*, inclu

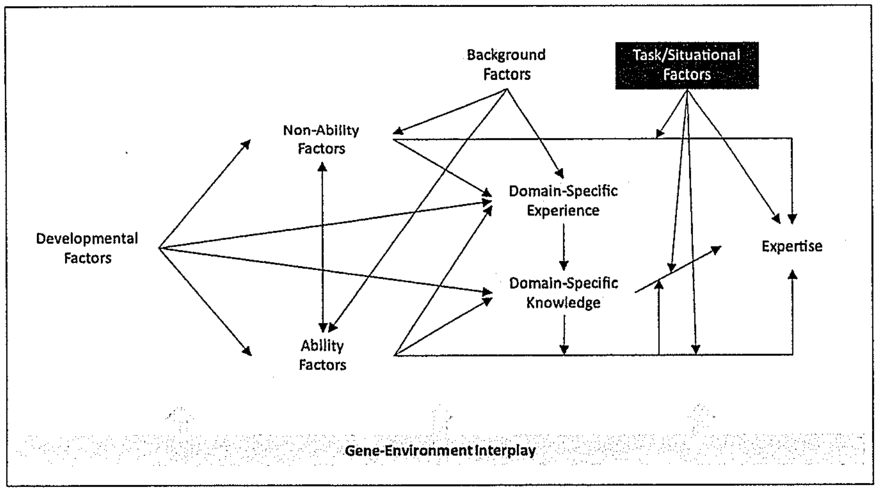

FIGURE 1.2 General framework for multifactorial perspective on expertise. See Hambrick *et al.* (2016) for an expanded version of this model.

specialized knowledge, skills, and strategies; (6) *domain-specific experience*, including training and other forms of experience; and (7) *task/situational factors*, such as task complexity, time pressure, the presence of external evaluation, and the predictability of the task environment. These factors can have both direct and indirect effects of the predictor constructs on expertise; also, genetic and environmental influences are assumed to operate throughout the model, leaving open the possibility that even factors such as training that are assumed to be purely "environmental" may have some genetic basis.

Overview of this Book

For us, the big picture created from all this recent research is that the "nature vs. nurture" debate in scientific research on expertise is over—or it certainly should be. We agree with Wai (2014) that "if we wish to appropriately represent the full network of evidence surrounding the acquisition of expertise, the phrase 'made, not born' really should be changed to 'born, then made'" (p. 74). With this overarching theme, this volume is the first attempt to bring together a collection of papers exploring the multifactorial nature of expertise; the contributors include 62 scientists, representing 39 institutions/organizations in 9 countries. What is particularly exciting is that much of the work discussed in the chapters is the contributors' own original research.

The book is organized into five parts. The first three parts cover the major approaches to research on expertise. Part I covers the *behavioral approach*. A primer chapter by Samuel McAbee and Frederick Oswald (Chapter 2)

(e.g., sample size, restriction of range, reliability). The following chapters
cuss the role of various ability and non-ability factors in expertise. Guille
Campitelli (Chapter 3) covers processes underlying chess expertise, w
James Staszewski analyzes expertise in Rubik's Cube solving (Chapter
Jonathan Wai and Harrison Kell (Chapter 5) discuss the role of intelligence
developing professional expertise. Joanne Ruthsatz and colleagues summa
findings from the largest-ever study of prodigies (Chapter 6). Jennifer D
and Ellen Winner (Chapter 7) give an update on the role of talent in draw
and Rebecca Chamberlain (Chapter 8) presents evidence from her multi
torial study of drawing expertise. Brooke Macnamara and colleagues (Chapte
end the section with a critique of the deliberate practice view of expertise

Part II covers the *neural approach*. A primer chapter by Alessandro G
and colleagues (Chapter 10) provides an overview of neuroimaging techniq
particularly as applied to expertise research. The next three chapters cover n
ral underpinnings of expertise in three domains. Merim Bilalić and colleag
(Chapter 11) discuss neural underpinnings of expertise in games such as Go
chess. Mackenzie Sunday and Isabel Gauthier (Chapter 12) cover percep
expertise—more specifically, expertise in object recognition in activities suc
identifying cars and birds. Ellen Kok and Anique de Bruin (Chapter 13) ider
neural correlates of motor expertise in real-world domains such as surgery.

Part III covers the *genetic approach*. In the primer chapter, Elliot Tucker-D
(Chapter 14) presents a framework for understanding the acquisition of ex
tise in terms of gene-environment interplay that draws on pioneering work
Robert Plomin, the author of the Foreword. The next three chapters ex
ine the role of genetic factors to expertise in specific domains. Lee Thomp
and colleagues (Chapter 15) review evidence for genetic and environme
contributions to reading and math expertise. Miriam Mosing, Isabelle Per
and Fredrik Ullén (Chapter 16) review evidence from twin studies for gen
influences on music expertise, while Yi Ting Tan, Gary McPherson, and Sa
Wilson (Chapter 17) identify specific genes that may underlie music expertis

Six theoretical models of expertise are presented in Part IV. The mo
address expertise from different perspectives, but all are multifactorial in
vor. Expanding his influential Differentiated Model of Giftedness and Ta
(DMGT), Françoys Gagné (Chapter 18) introduces the Integrative Mode
Talent Development (IMTD). Dean Simonton (Chapter 19) offers a ph
sophical analysis of the distinction between creativity and expertise. Fern
Gobet, Martyn Lloyd-Kelly, and Peter Lane (Chapter 20) explain the bene
of a computational approach to research on expertise. Fredrik Ullén, Mir
Mosing, and Zach Hambrick (Chapter 21) describe the Multifactorial Ge
Environment Interaction model of expertise. Arielle Bonneville-Roussy
Robert Vallerand (Chapter 22) present a conceptual model of the role of pass
in expertise. Karl Erickson, Jean Côté, and colleagues (Chapter 23) discuss
role of "deliberate play" in the context of their Developmental Model of Sp

Part V, the final section, presents commentaries on the other chapters, each by a scientist who has made an eminent contribution to the science of expertise. Robert Sternberg (Chapter 24) discusses the history of expertise research and distinguishes among four types of expertise—*analytical, creative, practical,* and *wisdom-based.* Reba Subotnick, Paula Olszewski-Kubilius, and Frank Worrell (Chapter 25) comment on giftedness and talent, offering their mega-model for talent development. Robert Proctor and Aiping Xiong (Chapter 26) link findings and ideas discussed in the chapters to the broader literature on skill acquisition. Finally, Robert Hoffmann (Chapter 27) discusses issues surrounding the definition and measurement of expertise, warning against "methodolatry"—growing too attached to a particular methodological approach.

Moving Ahead

Over the past decade, scientific interest in expertise has exploded. Empirical research generated by this interest has identified numerous factors that may contribute to variation in expertise, but little effort has been made to integrate these findings. Consequently, while it is obvious now that expertise is a puzzle with many pieces, it is not clear how these pieces fit together. We hope that this volume will encourage integrative thinking about expertise, and in so doing increase scientific collaboration toward understanding this topic that fascinates scientists and non-scientists alike.

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