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Development of expertise

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Synonyms

Acquisition of expertise

Definition

An expert is a person whose performance in a given domain is superior to that of the large majority of the population. Recursively, a super-expert is an expert whose performance is superior to that of the large majority of the expert population. The study of the development of expertise has been the province of psychology, but has also attracted interest in other fields such as biology, education, sociology, and artificial intelligence. While theories based on talent have emphasized fixed, innate traits, theories based on learning and practice have shed light on the path that developing experts have to travel. They have examined the types of knowledge that must be acquired, and the form that their acquisition takes over time.

Theoretical Background

In 1905, Albert Einstein wrote five articles that revolutionized the world of physics. Arthur Rimbaud stopped composing poetry at the age of 21. In just five years of writing he had revolutionized modern literature. In sport, Martina Hingis dominated female tennis from 1997 to 2002; she was the youngest player to be number one in the history of tennis. In chess, former world champion Garry Kasparov obtained the highest ratings of all times. His strength was such that he beat national teams, consisting of professional players, in simultaneous games. These examples illustrate super-experts – extreme cases of expertise. The label "expert" is also used, more modestly, with individuals such as physicians, PhDs, national champions in sports, and so on.

The fact that the term "expert" applies to such diverse kinds of people suggests that it might be problematic to define what exactly an expert is. One could define an expert as someone who attains performances at the level of an experienced professional; but to what does "experienced" refer? Does it refer to the amount of practice devoted to a domain or even to the number of years spent in the domain? However, time spent in a domain is a poor predictor of expertise. Think, for example, about those golf amateurs who have practiced for years but have never reached a high level of play. Similarly, the use of diplomas is problematic, because diplomas are based on sociocultural criteria, which are rarely objective measures of relevant performance. For example, diplomas in medicine are a reflection more of individuals' ability to study rather than an ability to diagnose and treat patients successfully.

The difficult task of classifying an expert is easier in some domains where official ratings are available. The best example is in the game of chess, which for decades has had a rating (the Elo rating) that precisely and quantitatively ranks players, from beginners to world champions. The presence of such a rating system (updated every few months) explains why so much expertise research has been made on chess. Unfortunately, such rating systems are rare, even in games and sports. To mitigate this rarity, researchers (e.g. in physics and medicine) have often used a simple dichotomy: novice vs. expert. While this is a practical solution, it loses much information. A further complication is that "expert" is a label that is sometimes given more for social reasons than for the skill level of an individual. The criteria may vary between societies or even within societies. This renders comparisons very difficult indeed. In some cases, whether somebody is an expert or not critically depends on the context: a fortune-teller is considered an expert in some societies but not in others. In some domains at least, the status of an expert is clear. A skeptic might doubt the expertise of a Roger Federer, but playing game of tennis against him would swiftly dispel any doubts.

The study of expertise is interesting and important for the sciences of learning, for several reasons. First, individuals who are capable of extraordinary performances offer a unique window on human cognition. Second, and related to the first point, these individuals can shed light on strategies to push the previously known limits of human cognition and rationality. These strategies can be of useful to other people, even non-experts. Third, studying experts can illuminate which training methods are efficient and which ones are not, again with applications for non-experts and even for education in general. Finally, a better understanding of the cognitive processes underpinning expertise and its development may help the development of artificial intelligent systems capable of performing at a level equal or even higher than the best human experts.

Extraordinary Performance

Talent	**Expertise**
Correlational studies	Experimentation and modeling
Psychology of intelligence	Cognitive psychology
Innate	Acquired
Differences between novices and experts	Similarities between novices and experts
Children/Adults	Adults
Normal and pathological	Normal

Table 1. Comparison of the two traditions that have dominated the study of exceptional performances: on the left, the talent approach; on the right, the expertise approach.

In psychology, two traditions have dominated the study of extraordinary performances: one based on the notion of talent, and the other based on the notion of expertise (see Table 1). The first tradition goes back to the 19^{th} century, with Gall's phrenology in Germany and the works of Galton in England. It aims to show that innate talent is necessary for high levels of performance. For example, researchers such as Eysenck in England and Jensen in the USA have suggested that intelligence quotient (IQ) correlates with the efficiency of elementary perceptual processes. This approach is characterized by the use of correlations, the use of data from neurobiology, and a focus on inter-individual differences. The second tradition has focused on the learning mechanisms and the environmental conditions that make possible the development of extraordinary performances. The emphasis is on adults and "normal" individuals, as opposed to individuals suffering from pathologies (e.g. autistic calculators). Rather than correlations, this approach uses laboratory experiments where experts are asked to carry out tasks representative of their skills. For example, given the description of a case, a physician is asked to carry out a diagnosis and venture a prognosis.

The experiments carried out by the expertise approach tend to use standard experimental paradigms in cognitive psychology. The focus is on the similarities between the performances of individuals of the same skill level, or even between the cognitive mechanisms used by individuals at different levels of expertise. Differences between individuals of different skill levels tend to be explained by differences in practice. Computational modeling is sometimes used to formalize the processes thought to underpin the development of expertise. In other words, a computer program is designed which *simulates* expert performance. The program is required to produce the same results as an actual human expert, and therefore needs to operate using the same cognitive processes as an actual human. In some cases, the computer models are able to reproduce the detail of the behavior at different levels of skill.

Sadly, there have been only few interchanges between these two traditions, and the rare examples have tended to highlight the disagreements rather than the possible commonalties (see for example Howe, Davidson & Sloboda's, 1998, article in *Behavioral and Brain Sciences* and the ensuing replies). Some rare authors (e.g., Macintosh, 1998) occupy an intermediate position on the continuum ranging from a pure hereditarian position to a pure environmentalist position.

Given its own research interests, the expertise tradition has had much more to say about the development of extraordinary performances than the talent approach, which emphasizes the role of traits that are essentially fixed. Starting with Binet in 1894, expertise development has been seen as the acquisition of knowledge. De Groot in 1946 described in more details the ways expert knowledge is organized, and also had the critical insight that knowledge is closely linked to perception. In 1964, Fitts proposed three stages in the acquisition of perceptual and motor skills. During the *cognitive phase*, rules, procedures, and facts are learned by instruction, trials and errors, and feed-back. During the *associative phase*, stimuli are associated with responses, and chains of responses are built. During the *autonomous phase*, behavior becomes self-sufficient and independent of cognitive control. Practice and feed-back play an essential role in the last two phases.

Building on the work of De Groot, Chase and Simon in 1973 proposed that knowledge is encoded as fairly small chunks <<Link to Chunking mechanisms and learning>>, fairly simple data structures. They also suggested that the development of knowledge consists of acquiring a large number (between 10,000 and 100,000) of these chunks. Some of the chunks are linked to potentially useful actions. Gobet and Simon in 1996 combined the idea of a chunk with that of a *schema*, proposing that the chunks that are used often by an expert become *templates*, more complex data structures akin to a schema, which consist both of fixed and variable information. Ericsson and colleagues have pushed to the extreme the position of the expertise approach, arguing that deliberate practice <<Link to Deliberate practice and its role in expertise development >> is sufficient to attain high levels of expertise.

In line with Chase and Simon's account, Newell and Rosenbloom proposed in 1981 that expertise is the product of the acquisition of a large number of productions – simple rules consisting of a *condition* and an *action*. Combining computational and mathematical modeling, they showed that, following the principle of diminishing returns, accretion of chunks leads to a power law of learning in performance; that is, there are rapid improvements at the beginning, followed by increasingly slower improvements thereafter.

Important Scientific Research and Open Questions

In spite of considerable research in the last decades, the field of expertise faces a number of open questions and challenges. As noted above, defining expertise has turned out to be tricky, and, in many domains, a better operationalization of this concept is desirable. The interaction between environment and the cognitive processes engaged by experts is rarely well understood. At the extreme, it could be argued that studying experts will tell us little about the cognitive mechanisms underpinning expertise, but much about the domain itself – the structure of the environment. For example, will observing biologists reveal anything about their thinking beyond what could be found in a biology textbook? Obviously, students of expertise believe this is the case, but stronger evidence than that collected so far would be welcome.

While far from being resolved, the debate between *talent* and *practice*, one the many variations of the great debate between *innate* and *acquired*, has gained in momentum with the rapid advances in neuroscience and genomics in the last decades. The results seem to bring support and comfort for both camps. On the talent side, the developments in genomics make it hard to doubt the role of genes in individual differences, including differences between the best individuals in a domain. On the expertise/practice side, the developments in neuroscience have highlighted the plasticity of the brain and its remarkable ability to learn. Given the complexity of these results, together with the complexity of the results collected in expertise research itself, it is likely that the only way forward is to use some form of computational modeling. Finally, one of the great unknowns in this field is whether there are stages in the development of expertise, as proposed for example by the early work of Bryan and Harter in 1899 on telegraphy. The presence of power laws seems to suggest that expertise development is continuous, but stages keep appearing in theories of expertise.

Cross-References

→ Bounded rationality and learning
→ Chunking mechanisms and learning
→ Development of expertise
→ Individual differences in learning
→ Learning in Practice
→ Learning in the CHREST cognitive architecture
→ Schema

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Definitions

<u>Expert:</u> A person whose performance in a particular domain is superior to that of the large majority of the population.

<u>Expertise</u>: The field of research investigating the cognitive processes behind exceptional performance.

Talent: The framework proposing that extraordinary performance is primarily due to innate abilities.

Production: A rule consisting of a set of conditions and a set of actions, which fires when the conditions are met. A *production system* is a model consisting of a set of productions.