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Expert Characteristics: Implications for Expert Systems

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Abstract

While expert systems are artificial intelligence (AI) agents, they share many common characteristics with human experts. As technology progresses, such systems are not just able to make simple decisions following "simplistic" linear logical protocols; they "behave" as real experts in at least two ways: by demonstrating superb decision-making skills and by conforming to the social norms for expertise, i.e., they "feel" as human experts. A review of the common characteristics of human experts may have important implications for the direction of the development for such systems. Implications for bioinformatics and future research (especially concerning the accompanying concept of "expert generalist") are also discussed.

Keywords

Expert generalist · Expert systems · Methodology of science · Epistēmē

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1 Introduction

The study of expertise and expert performance (Science of Exceptional Achievement) is a new and broadly recognized field. It is mostly concerned with the biological substrate of expertise but also with the behavioral characteristics of experts [13, 32]. The sociological study of expertise is somewhat older and is also related to many classic – and to some extent, "heretic" – works [8, 26].

The paper starts by exploring the common characteristics of expert specialists as presented in the scientific literature. Implications for expert systems are then discussed. Future directions are given in relation to the novel concept of the contributory expert generalist.

2 Inside the Expert

Experts not only know more but differently as well [15, p. 57]. Here, many of the reasons for this ontological difference will be discussed. It should be noted, however, that the main characteristic of experts is their *actions*; expertise is not demonstrated by what an expert thinks, feels, or "is." Only actions are known to us and only through them can individuals (or AI agents) be granted the "expert" title.

Two lines of confusion emerge. The first one being what kind of action precisely makes some-

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one an expert. This paper is dedicated to the exploration of this question. Tools, such as the *expert-performance approach* developed by K.A. Ericsson [14, p. 347], may be used for this kind of research. Ericsson et al.'s approach includes the standardization of characteristic expert tasks for in-lab reproduction and assessment.

Another example is the periodic table of expertise as was proposed by Harry Collins and Robert Evans [7], which includes concepts such as interactional expertise that help make explicit the differences between different kinds of experts, as well as their strengths and weaknesses.

So, what makes an expert, expert? An expert can sometimes be perceived as a black box whose outputs are known but its functions are hidden. In what follows, we will attempt to elucidate some important mechanisms of this "black box."

The simplest way to avoid (but not to eliminate) value judgments about the nature of expertise is to have a dual approach: construct a biological and social (and sociobiological) model of expertise a priori and only then to attempt and measure expertise parameters in real life.

2.1 Specificity and Creativity in Experts

Expertise is highly specific and does not generalize even to seemingly similar tasks and activities. The most widespread type of expertise in humans is a tacit (interactional) one – the ability to identify patterns in particular and faces in general [22, p. 667–68; 28]. This type of expertise is so specialized that the fusiform face area[1] activates differently even in the case of different-race faces. Hill and Schneider (p. 673) describe how the brain of male ballet dancers activates differently when viewing "male" ballet movements in relation to "female" ballet movements, as indeed the style of each sex is somewhat different (e.g., female ballet dancers execute more movements on their toes). This very specialized encoding will the foundation for learning a motor skill. The implications of this ability also relate to the very strict limits of generalization between categories and the exclusive nature of expertise [4].

In regard to the generalizability of "mental functions," already from 1901, Thorndike and Woodworth, in a classic paper, refuted the then-popular idea that students may readily generalize their competence from one subject to others, and, for instance, learn Latin to become "generally more intelligent" (an enduring idea). As Thorndike and Woodworth concluded: "The functions of judging nearly equal magnitudes are, sometimes at least, largely separate and independent. A high degree of ability in one sometimes coexists with a low degree of ability in the others" [50, p. 260].

The research concerning specificity continued the decades after Thorndike and Woodworth's research, most notably with Franklin Henry, who extended the findings to motor skills [2, p. 3–4]. The "specificity hypothesis," as Bain and McGown [2] argue, "may be as close to a law as any principle in motor learning science." However, some transfer of perceptual skill across sports with similar perceptual demands has been observed [45, p. 205] as well as a possible selective transfer of pattern recall skills, with implications for the value of cross-training – should these possibilities be confirmed [1, p. 205]. Finally, Schöllhorn et al. [41] treat diverse influences as perturbations that foster learning, as was the case with Taleb's antifragility concept which applies to every system that improves when facing unexpected situations rather than fail [41, 48].

A similar point has been made for cognitive skills. After studying 40 male scientists, including four Nobel Prize winners, one of the aims of Root-Bernstein et al. was to determine whether Gruber's concept of networks of enterprise holds [18, 35, p. 246]. One of the findings was that "scientists in general are more likely to make their breakthroughs while working on unrelated problems and away from their workplace than they are while directly addressing a problem in their laboratory" [35, p. 867], leaving open the possibility that "intensive training and focus on single

[1] FFA – the area in brain that increases its activity in response to face detection.

tasks for long periods of time may be seriously detrimental to creativity" [35, p. 867].

Feltovich et al. [15] return to the topic arguing that "there is little transfer from high-level proficiency in one domain to proficiency in other domains – even when the domains seem, intuitively, very similar." This resembles the discussion about interactional experts who might seem to be (contributory) experts in related fields (even themselves believing that to be the case), lacking, however, important tools that would allow them any serious participation on the level of the contributing experts in their corresponding field. The disconnection from the scientific community only enlarges this problem. This is seen not only in sciences (such as medicine where the same physicians showed great variety in assessment skills depending on specific experience with different kinds of cases – [15, p. 47] but in games as well, even in variations of the same game, or in the same game and rules, played with different amounts of people or different environments or different periods. The ability to teach a private tennis lesson is distinctively dissimilar to the ability to keep a group actively engaged [51].

Specificity and creativity seem to take opposite routes, as a creator usually is considered to be broad-minded [42] and the expert's view restricted to their narrow and specific field. After all, specificity is important for the expert, and certainly, extensive knowledge is also important [15, p. 49]. But as it has been established until now, a broad mindset is a prerequisite for success in creative performance as well as in expertise [42, p. 171, 44, p. 3], and in creative performers, knowledge matters too since "chance favors only the prepared mind," as Pasteur eloquently put it.

Creativity is a distinct characteristic of experts, either seen as an expression of the Zeitgeist [43, p. 168] or as the specific product of personality, talent, skill acquisition, practice, experience, and opportunity as a strategy for problem-finding and problem-solving [35, p. 865]; this applies to both creative and "non"-creative expert fields (e.g., writing novels requires more creativity than driving a taxi). Simonton discusses how the most creative scientists engage in a variety of extracurricular activities, being this way more able to "think outside the box" [44, p. 3]. Therefore, one would expect creativity and specificity to be somehow connected (e.g., one to be particularly creative in his/her field of expertise rather than "generally" creative).

Still, creativity is distinct from expertise, as many researchers argue. Simonton characteristically argues that "taken together, the three criteria of creativity raise serious doubts about whether exceptional creative performance can be easily and exhaustively subsumed under an expertise acquisition framework" [44, p. 3]. As [35, p. 858] notices, creativity "is inherently multimodal, trans-disciplinary, and independent of domains," which could be contrasted with expertise that is highly domain-specific. Mere repetitions, even proficiently, of an activity will not make a better expert out of someone – rather the opposite [10, p. 683].

The interconnection of so many parameters (including possibilities examined next) makes both cognitive and physical (e.g., athletic) domains immune to strong effects from any one single factor [38, p. 764] – a motif that makes any talent-related discussion fundamentally problematic.

2.2 Abilities

Experts have advanced some abilities into expert skills. Apart from the approximately 30 identified cognitive and motor abilities, more are constantly being discovered or being made up [40, p. 165], and among researchers, a great deal of controversy exists [9, p. 84]. One should bear in mind, however, that for expertise, domain-specific experience is of the utmost importance, rather than natural abilities associated with IQ and superior memory in general [23, p. 478].

Starting from cognitive abilities, one of the most discussed is G – general intelligence factor – as measured by IQ tests. There is a general consensus about the validity of the G model, even if there are some objections regarding its ecological validity [20, p. 493; 9, 83].

2.2.1 G-Factor

John Carroll proposes a three strata composition of intelligence by means of a pyramid [5]. The mental ability exists on top and is analyzed in Stratum II, which consists of eight more specialized abilities, which in turn are further analyzed in Stratum III in about 70 specific abilities. Carroll viewed these abilities as capacities as well, partly predefined – although he was open to the view that the environment could play a major role [29, p. 15–16].

The two most discussed Stratum II abilities are: fluid intelligence (Gf), that includes inductive reasoning, i.e. the broad ability to form concepts, solve problems, and cope with novelty and crystallized intelligence (Gc), which is related to verbal comprehension, the breadth and depth of a person's acquired knowledge, and the ability to reason, counting on experience.

2.2.2 Theory of Multiple Intelligences

Howard Gardner has based his theory of multiple intelligences in studies of normal and pathological children/adults and of gifted and "idiot savants" as well as in a wide variety of cultures [16, p. 5]. Multiple intelligence theory postulates there are at least eight relatively autonomous intelligences (with their own evolutionary path), which are often interactive, have evolved with the human species, and are valued in a wide variety of cultures [9, p. 83].

2.2.3 Triarchic Theory of Successful Intelligence

Robert Sternberg proposed his own Triarchic Theory of Successful Intelligence. A theory that is more complex than the ones discussed focusing on the mechanisms, rather than the specific domains. Interculturally, Sternberg theorizes that intelligence meant the success of the individual in adapting to his/her environment [47].

2.2.4 Other Theories

As noted before, the exact structure of basic abilities is debatable, and every researcher adopts some variation that expresses their research-focus better. For example, Wallace and Maker [52] present their own ten abilities that better suit their educational interests. This categorization is even more general, including physical abilities [52, p. 1133–37]:

- Social/humanitarian
- Spiritual
- Emotional
- Mathematical/symbolic
- Linguistic/symbolic
- Scientific/realistic
- Mechanical/technical
- Visual/spatial
- Auditory/sonal
- Movement/somatic

In physical abilities there may be some debate – does a "singular global ability" or a "general timing ability" exist? – but the consensus is broader than in cognitive abilities. This may be seen from the taxonomies of physical-motor abilities that haven't changed much since Edwin Fleishman's grouping in the 1960s, with the most known addition being that of Keele and his colleagues in the 1980s [40, p. 172–73]. The existence of general, nonspecific abilities, inspired by the general ability in cognitive abilities, has not been confirmed [40, p. 166 & 173].

3 A Brief Study of Expert Memory

Knowledge is a distinguishing characteristic of experts. "Acquired domain knowledge has been the most prominent explanation for the superiority of expert performance" [27, p. 464–65]. Knowledge of this sort is stored in the long-term memory (LTM). Experts have developed their LTM retention for domain-related material even if memorization per se is not their direct goal; for example, the central nervous system of musicians undergoes substantial functional and structural changes with consequently altered processing capabilities [27]. Due to exactly these adaptations, musicians characteristically suffer from neurological problems when the limits of neuroplastic changes are exceeded [27].

LTM is not the only kind of memory experts highly develop. De Groot, an early pioneer of the second half of the previous century, describes –

apart from his findings of chess players – many other experiments conducted by various of his colleagues (Binet, Djakow, etc.) who tried to elucidate the player's phenomenal "visual" memory [17]. The researcher's interest was caught by the amazing memory of the grandmasters who were able, for example, to play blindfolded against as many as 15 opponents.

One may find many examples of incredible expert memory – from Homer (if he existed) and the rest of the singers in ancient times that could recite by heart epic songs like *Homer's Odyssey* and *Iliad* to contemporary piano players and actors who have developed a unique ability to process items in their own working memory. These achievements blur the traditional limits of working memory, and, as Ericsson and Kintsch propose, individuals develop a new memory skill in order to "meet the particular memory demands of a complex, cognitive activity in a particular domain," i.e., long-term working memory (LTWM – [11, 12]).

LTWM is not only important for performing tasks such as playing chess or conducting a symphonic orchestra but for coping with more "classic" scientific activities, such as encoding a new symptom during an interview with a patient in LTWM in a way that will enable the physician to automatically access all the previous and forthcoming data from the patient and reason for the therapy [15, p. 54]. This way of coding information gives an advantage to scientists such as medical doctors when having to answer questions not like "given the disease what is the therapy" (which merely utilize long-term memory), but the much more complex one "given the patient, what is the disease?" Such a question needs an active mental synthesis of data presented over a long interview – one that may be interrupted and restarted many times over [15, p. 55]. This point is particularly important to expert systems in bioinformatics since they will be called to deal with similar diagnostic tasks.

Of course, it is not only memory capacity that counts but its content as well. A characteristic case is Chao Lu, the Guinness world record holder for reciting 67,890 digits of Hu et al. found that Lu exhibited a memory digit span (a chunk) within the normal range, which is around eight digits [24]. The ability to chunk information into meaningful wholes or patterns of tactical significance and chunk it differently and better from novices as well has been proposed to facilitate decision-making performance in experts [46, p. 184 & 187; 49, p. 195 & 199–200].

3.1 Expert Processing of Stimuli

The studies of Haier indicate that high-IQ individuals undergo physical changes in their brains that include both structural (more grey matter in the discrete Brodmann areas – [19]) and metabolic (better energy efficiency – [21]) adaptations [19, 21]. Motor skill learning is related to plastic changes in the brain as well [39, p. 423]. Therefore, one might expect that the same could be the case with experts. Indeed, Hill and Schneider [22] summarize six reoccurring themes in learning literature that apply to expertise [22, p. 658]:

1. Learning is localized and very specialized.
2. Learning and processing occur in the same cortical locations.
3. Learning can produce both increases and decreases in the areas of activation.
4. In some tasks there is a reorganization of the task that involves different brain regions when alternate strategies are used.
5. Behaviorally relevant objects and other stimuli are uniquely processed by experts.
6. Learning can produce detectable morphological changes.

Experts learn to encode stimuli according to their importance, which makes possible the development of the critical characteristic of selectivity [15, p. 55]. The process of prioritizing environmental stimuli has been learned from experts in such a way that they automatically prioritize relevant stimuli from the environment, which affords them better attention to relevant clues that will help them make better recognition-primed decisions (RPD) [22, 36, p. 406].

When the process of prioritization has become automated, while the performers improve their skills, the attentional demands diminish as well

[40, p. 213]. This improvement is evident as decreased activation patterns in the brains of skilled individuals occur, in relation to both novices and intermediates. fMRI images depicting the axial plane of the brain shows these dramatic reductions in activation [22, p. 654].

Faster and more accurate responses are characteristics of experts and have been measured in a variety of activities, especially in medical diagnosis (e.g., X-ray diagnosis – [6, p. 173]). One result of the experts' privileged vision is that they exhibit the quiet eye phenomenon, that is, they need to observe fewer items (fewer eye fixations) that are perceived to be "informatively rich" in their environment to make proper decisions [23, p. 476].

Experts also use reflection to adapt to situations with an "unencumbered elegance" [15]. Reflection has implications for motor control as it is closely related to the cerebellar-prefrontal associative system [37, p. 209].

Maybe the aforementioned implicit-automated processes help explain the "sense" experts have, their intuition, and their ability to complete the task with whatever resources available – a set of skills known as bricolage [25, p. 282]. Moxley et al. cite to explain how important intuition is for expert chess players: "Serious tournament chess involves deep deliberation, although…the quality of move choice depends surprisingly little on anything beyond pure intuitive response" [30, p. 73].

4 Expert(ise) Characteristics

Are there enduring traits among the experts identified by the relevant literature? In brief, the characteristics that were identified until now from the former discussion are presented firstly.

1. Experts know more and differently.
2. Expertise science concerns itself with the specialized behavior an expert is able to demonstrate.
3. Experts with increased creativity perform generally better, and (complementary) broad influences are beneficial.
4. No single ability/intelligence is more important for an expert.
5. Experts are characterized by extensive memory skills relevant to their domain.
6. Experts have the capacity to take automated decisions that may seem counterintuitive to the nonexpert but nevertheless are appropriate.
7. Experts are intuitive and resourceful.
8. Experts have a "growth" mindset that is competitiveness-oriented.
9. Experts are indirectly defined through the criteria and needs society has.

Next, we will retrieve from research findings the common characteristics of experts and expertise performance.

4.1 A Compilation of Expert Characteristics

In the 2004 publication, *How People Learn: Brain, Mind, Experience, and School*, the US National Research Council considers several key principles of experts' knowledge and their potential implications for learning and instruction [3, p. 31]:

1. Experts notice features and meaningful patterns of information that are not noticed by novices.
2. Experts have acquired a great deal of content knowledge that is organized in ways that reflect a deep understanding of their subject matter.
3. Experts' knowledge cannot be reduced to sets of isolated facts or propositions but, instead, reflects contexts of applicability: that is, the knowledge is "conditionalized" on a set of circumstances.
4. Experts are able to flexibly retrieve important aspects of their knowledge with little attentional effort.
5. Though experts know their disciplines thoroughly, this does not guarantee that they are able to teach others.
6. Experts have varying levels of flexibility in their approach to new situations.

Rossum [38, p. 762] offers a list of characteristics, as is presented in the literature, that may be more applicable to younger achievers:

1. Commitment and self-confidence [31]
2. Fast learning [53]
3. Precocity, an insistence on marching to their own drummer, a rage to master [53]

Terry Orlick has developed his own model of "excellence." Its main axons are [31, p. 12]:

1. Commitment
2. Belief/self-confidence
3. Full focus
4. Positive images
5. Mental readiness
6. Distraction control
7. Constructive evaluation
8. Ongoing learning

Toward the presentation of generalizable characteristics of expertise is the effort of Feltovich et al. In an article about the "Studies of Expertise from Psychological Perspectives," they discuss a series of ten characteristics [10, p. 46–60]:

1. Expertise is limited in its scope and elite performance does not transfer.
2. Knowledge and content matter are important to expertise.
3. Expertise involves larger and more integrated cognitive units.
4. Expertise involves the acquisition of a large vocabulary.
5. Expertise involves functional, abstracted representations of presented information.
6. Expertise involves automated basic strokes.
7. Expertise involves selective access of relevant information.
8. Expertise involves reflection.
9. Expertise is an adaptation.
10. Simple experience is not sufficient for the development of expertise.

Simonton, in the *Origins of Genius* [43], mentions throughout the book characteristics of experts:

1. p. 29: "[C]ombinatory play seems to be the essential feature in productive thought" (Einstein).
2. p. 31: Janusian Thinking: actively conceiving two or more opposite or antithetical ideas, images, or concepts simultaneously.
3. p. 114: [A balanced childhood] "There's only one thing that's worse than having an unhappy childhood, and that's having a too-happy childhood." [Simonton cites Dylan Thomas]

and six characteristics that are more likely to appear to creative persons, or whoever has these characteristics is more prone to creative thinking [[43, p. 90]:

1. Highly creative people harbor an impressive array of intellectual, cultural, and aesthetic interests.
2. Highly creative individuals are widely open to novel, complex, and ambiguous stimuli in their surroundings.
3. Highly creative people are capable of defocused attention.
4. Highly creative individuals are unusually flexible both cognitively and behaviorally.
5. Highly creative people are introverted.
6. Highly creative individuals are independent, autonomous, unconventional, and perhaps even iconoclastic.

Kalbfleisch [25] also refers to Einstein's characteristics (like [43]) and cites a series of researchers to support that: "Indeed, one hallmark of creative giftedness is the ability to remain resilient and child-like, to suspend reason or entertain multiple forms of it during the intentional [volitional] wrestling with a thought and the unintentional [incubatory, non-volitional] tumbling of ordinary bits of knowledge while awake and asleep that amalgamate in the moment of 'aha!'."

Two characteristics M.J. Rossano [37] refers to are both related to the level of expert deliberate practice characteristics. He contends that [37, p. 219 & 227]:

1. [A]n expert must be ever able to inhibit initial, automatic responses to sensory data in order to retain the flexibility necessary to react effectively to changing circumstances.
2. Experts always retain a certain degree of conscious, intentional control over the actions in their domain.
3. An essential element of deliberate practice (and thus of skill acquisition) is the ability to

focus awareness inward, away from the environment and onto one's own actions .

5 Expert Characteristics and Expert Systems

This paper will conclude with a comparison of the characteristics presented in the previous paragraphs. The most common characteristics will be included; implications for expert systems will be discussed.

1. Expertise is specific.
   Implications for expert systems: the field of expertise should be accurately described.
2. Expert concentration (ability to highly and properly concentrate).
   Implications for expert systems: AI agents should analyze only the most relevant cues from the environment (or from the databases they use); otherwise the probability for false positive or false negative diagnosis increases.
3. Experts are adaptive.
   Implications for expert systems: merely achieving a high level of automatization is not enough if it cannot be adaptive. How could adaptiveness be expressed in terms of AI? It could be by the use of adaptive algorithms that change their behavior in real-time based on, e.g., pre-determined criteria. One such way is to use a logic system that has minimally four truth values; therefore, it may be able to "see" fewer contradictions and become more adaptive in regard to accommodating more data.
4. Experts have a unique memory system.
   Implications for expert systems: the accumulation of data is not enough; the structure of the accruing information (or knowledge if expert systems can "know") is equally important. To that end, the formal logic system must be such that supports sound inference methods.
5. Experts keep learning.
   Implications for expert systems: Unexpected situations should always be accommodated. Apart from refreshing their data sources often, expert systems should use potent self-learning algorithms.
6. Experts are creative.
   Implications for expert systems: AI agents should combine past knowledge in different ways, combine past knowledge with newly gained one or create new knowledge (via probabilistic mechanisms?).
7. Experts depend on conscious cognitive skills.
   Implications for expert systems: research on consciousness should continue, and its implications should be applied to expert systems.

The crucial difference between interactional experts and contributory experts must also be taken into account [7]; both types of experts are important but for different reasons. Expertise, as is discussed here, is of the contributory, decision-making type. Interactional expertise is the one used for identification purposes (e.g., the pathologist is also an interactional expert in all other medical fields and can recognize to whom they should redirect a patient with certain symptoms). Yet another, much less discussed kind of expert should be identified: the expert generalist who is able to get involved in exclusive higher-level decision-making. For example, a pathologist who gives a generic treatment to someone who has an ACL injury (painkillers and anti-inflammatory drugs), refers them to the orthopedic surgeon but also advises the patient not to do surgery if they don't have any joint instability, is an expert generalist. There is very limited research regarding generalists; however, their existence is necessitated by the methodology used in epistēmē.

6 The Contributory Expert Generalist

Epistēmē is based on theory; its method is the dual pair of analysis-synthesis/abstraction-structure, and its starting point is not experience (as is the case with science) but general surveillance, or overview [33]. For epistēmē, the broader possible overview of general methodological principles is not only desired but obligatory. There are no "theories," no "truths." The desideratum in epistēmē is also to become a generalist, to be able not to miss anything – which is the etymology of alēthēa = truth [34].

Since the methodology used in epistēmē is dual, its first part is specializing (analysis), and the second one is generalizing (synthesis). Expert specialists may be said to express analysis, and expert generalists may be said to express synthesis (to avoid confusion, both kinds of experts should do both analysis and synthesis themselves when studying a phenomenon!).

7 Conclusion

"Expert decisions" the desired output of expert systems are the result of a series of preconditions and characteristics. Here, the characteristics of human experts have been described and some implications for their machine counterparts have been proposed. Future research needs to examine more closely the technical aspect of the implications discussed here.

The notion of expert generalist has also been described. What would that mean for an expert system? Should that mean a kind of cooperation between different expert systems (which is impossible for humans since they are not "interlinked" to each other but rather have separate minds)? Or should there be separate systems that act as "expert generalist systems"? That should also be revealed by future research.

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