Competence in Experts:
The Role of Task Characteristics

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Abstract

The previous literature on experts presents two contrasting views. Judgment and decision research has shown that experts make flawed decisions due, in part, to the biasing effects of judgmental heuristics. Cognitive science research, in contrast, views experts as competent and different from novices in nearly every aspect of cognitive functioning. An alternative view developed here, the Theory of Expert Competence, suggests that both analyses are correct, but incomplete. In particular, the theory assumes competence depends on five components: (1) a sufficient knowledge of the domain, (2) the psychological traits associated with experts, (3) the cognitive skills necessary to make tough decisions, (4) the ability to use appropriate decision strategies, and (5) a task with suitable characteristics. The latter is the focus of this paper.

Insufficient attention has been paid to task and domain characteristics in prior research. Decision researchers have looked primarily at experts in behavioral domains (e.g., clinical psychology), whereas cognitive investigators have concentrated on experts in static domains (e.g., physics). Thus, the discrepancy in the conclusions drawn from the two literatures appears to be a function of the different domains studied. Although similar to approaches such as Cognitive Continuum Theory, the proposed theory contains several new components. In addition, the theory has implications both for the analysis of experts and for the design and use of expert systems.

Competence in Experts: The Role of Task Characteristics

"Experto credito" (Virgil, 19 B.C.).

"No lesson seems to be so deeply inculcated by the experience of life as that you never should trust experts" (Lord Salisbury, 1877).

These quotes illustrate two facts: First, the topic of experts has been of interest to writers over the centuries. Second, there is considerable disagreement about the competence of experts. The purpose of this proposal is to explore expertise from an alternative perspective and to use that perspective to provide new insights on the competence of experts.

The paper is organized into five sections. The first section summarizes the prevailing views of experts in the judgment/decision making and cognitive science literatures. The second presents proposed definitions of "expert" and "competence." The next develops a new Theory of Expert Competence, with an emphasis on task characteristics. The fourth section compares the proposed approach to Cognitive Continuum Theory (Hammond, 1966). The final section considers implications of these observations for analyses of experts and for design of expert systems.

BACKGROUND

Decision-Making Research

With some exceptions, the judgment and decision making literature paints a dismal picture of the ability of experts. Deficiencies have been reported in nearly every type of decision analysis. The following provides a brief overview of the literature; for more a detailed account, see Shanteau (1989).

Psychometric analyses revealed that judgments by experts are lacking in validity (Oskamp, 1965) and reliability (Trumbo, Adams, Milner, & Schipper, 1962). Similar findings have been reported for a variety of experts, such as agricultural judges (Foss, Wright, & Coles, 1975), medical doctors (Einhorn, 1974), clinical psychologists (Oskamp, 1962), parole board members (Carroll & Payne, 1976), and court judges (Ebbesen & Konecni, 1975). Moreover, the experience of experts is not related to their judging ability (Meehl, 1954).

Studies of probabilistic judgments have reported deficiencies in calibra-tion (Christensen-Szalanski & Bushyhead, 1981) and coherence (Chan, 1982). Comparable deficiencies have been reported for various experts, including physicians (DeSmet, Fryback, & Thornbury, 1979), clinical psychologists (Lichtenstein & Fischhoff, 1977), meteorologists (Williams, 1951), forecasters (Lichtenstein, Fischhoff, & Phillips, 1982), and nurses (Grier, 1976).

Another approach to analyzing expert judgment is to examine the amount of information used in making decisions; presumably, experts should use all relevant information. Various studies, however, have reported that models of experts reflect surprisingly low information use (Goldberg, 1970). Under use of available information has been reported for criminal court judges (Ebbesen & Konecni, 1975), medical pathologists (Einhorn, 1974), and clinical psychologists (Goldberg, 1970).

Not only do experts make use of little information, the evidence suggests their judgments can be described by simple linear models. After reviewing studies from a variety of domains, Dawes and Corrigan (1974) concluded “the whole trick is to decide what variables to look at and then to know how to add.” Thus, expert judgments lack the complexity expected from superior decision makers. Moreover, experts apparently are unaware of their shortcomings (Meehl, 1954).

A common explanation for this low level of performance is that experts often rely on heuristics, which in turn lead to systematic biases (Kahneman, Slovic, & Tversky, 1982). Because of heuristic decision strategies, experts apparently are limited in the same way as naive subjects (Tversky & Kahneman, 1971). "Numerous studies show that intelligent people have great difficulty judging probabilities, making predictions, and otherwise, attempting to cope with uncertainty. Frequently these difficulties can be traced to the use of judgmental heuristics" (Slovic, Fischhoff, & Lichtenstein, 1985).

There have been some exceptions to the general trend of expert incompetence. Weather forecasters' predictions were reported by Murphy and Winkler (1977) to be well calibrated. Phelps and Shanteau (1978) found that livestock judges were capable of using large amounts of information. Medical doctors were observed by Christensen-Szalanski, Diehr, Bushyhead, and Wood (1982) to make good decisions. Research with auditors has produced many examples of competent performance (Ashton, 1983). These examples of strong performance, however, have been largely ignored in the literature (Christensen-Szalanski & Beach, 1984).

Altogether, previous decision making research presents a discouraging view of the abilities of experts. Kahneman (1991) stated a widely held conclusion: "There is much evidence that experts are not immune to the cognitive illusions that affect other people."

Cognitive-Science Research

A quite different view of experts has emerged from research in cognitive psychology. Studies within this tradition have shown expert superiority over novices in nearly every aspect of cognitive functioning, from memory and learning to problem solving and reasoning (Anderson, 1981). Chess masters, for instance, have been found to perceive patterns of play more effectively (deGroot, 1965) and to have better memory for chess positions (Chase & Simon, 1973). Experts in physics, mathematics, and computer programming reveal similar superior skills (Mayer, 1983).

Several themes have emerged from this body of research. First, expertise is domain specific. The special skills of an expert are diminished outside his/her area of expertise: "Chess experts do not appear to be better thinkers for all their genius in chess" (Anderson, 1990). Apparently, the thinking of experts is "domain adapted" (Slatter, 1987).

Second, expertise is acquired through stages of development, somewhat akin to the mental development of children. According to Fitts and Posner (1967), the first is the "cognitive stage," where specific facts are memorized to perform the task. The next is the "associative stage," where connections between successful elements are strengthened. The last is the "autonomous stage," where the skills become practiced and rapid.

Third, experts use different thinking strategies. For instance, novices have been found to reason backwards from the unknowns to the givens in solving physics problems. Expert physicists, in contrast, reason forward using stored "functional units" from the givens to the goal (Larkin, 1979). Therefore, expertise produces more efficient approaches to thinking about problem solving and decision making (Anderson, 1990).

Fourth, the thinking of experts is more automated (Shiffrin & Schneider, 1977). These automated processes generally operate in parallel and function somewhat like visual perception or pattern recognition. Novices, in contrast, rely on controlled processes, which are linear and sequential, more like deductive reasoning (Larkin, McDermott, Simon, & Simon, 1980).

Because of their special abilities, expert processes are reflected by and can be studied through verbal protocols. By asking experts to think aloud, qualitatively rich accounts of an expert' s reasoning processes become accessible (Ericsson & Simon, 1980). Although other methods have been proposed (Hoffman, 1987), protocol analyses are commonly used to provide the raw data for building expert systems (Slatter, 1987).

In total, the cognitive science view is that experts within their domains are skilled, competent, and think in qualitatively different ways than novices (Anderson, 1981; Chi, Glaser, & Farr, 1988). This skill can be tapped to provide a sufficient basis for building an expert system (Coombs, 1984).

SOME DEFINITIONS

Before trying to resolve these different views of expertise, it is necessary to define several key terms. The definition of <u>expert</u> is an obvious precondition to any analysis of expertise. Unfortunately, efforts to provide objective definitions have proved elusive. There are almost as many definitions of "expert" as there are researchers who study them (Hoffman, Shanteau, Burton, Shadbolt, & Akerstrom, 1991). Moreover, numerous hierarchies have been proposed to describe lower and intermediate levels of expertise (e.g., Benner, 1984; Dreyfus & Dreyfus, 1986).

My suggestion (Shanteau, 1987a) is to let those in a domain define the experts. In every field, there are some who are considered by their peers to be best at what they do. In some domains this is reflected by official recognition or job titles. In others, it comes from consensual acclamation. In my research, experts are operationally defined as those who have been recognized within their profession as having the necessary skills and abilities to perform at the highest level.

In contrast, a <u>naive</u> decision maker has little or no skill in making decisions in a specific area. For instance, undergraduate students generally are naive about the kinds of decisions made by experts. <u>Novices</u> are intermediate in skill and knowledge; they frequently have studied for years and may even work at sub-expert levels. However, novices lack one or more of the abilities needed to function as experts. Typically, advanced (graduate) students are novices in making skilled decisions.

From this view, much research on “experts” in fact has used novices. Thus, many “expert-novice” studies are better described as “novice-naive” studies. Further, it appears that at least some functioning expert systems mistakenly have been based on novices instead of experts (Levitt, 1991).

Defining the quality or competence of a decision is also difficult. This would be easy if standards existed for determining what is a good decision and what is not. Unfortunately, external standards are seldom available for expert domains -- that’s why experts were needed in the first place.

Even where objective criteria exist, they can be elusive and subject to debate. The problem is that standards are defined from subjective opinions of experts (not the other way around). And these opinions can shift over time, because circumstances change or experts adopt new standards.

My resolution is to rely on the views of acknowledged experts about what is a competent decision and what is not. These opinions are backed up by professional guidelines and commonly accepted standards in the field. Although there is some danger of circularity, this approach has been used successfully in many studies of experts.

THEORY OF EXPERT COMPETENCE

In my research, the primary research question has been: What factors lead experts to do well and what factors lead them to do poorly? My view is that experts are neither as deficient as suggested in the decision making literature nor as unique as implied by the cognitive science perspective. Instead, according to the Theory of Expert Competence, the skills and abilities that emerge (or don' t emerge) in experts depend on five factors: domain knowledge, psychological traits, cognitive skills, decision strategies, and task characteristics. The specifics of this theory are described elsewhere (Shanteau, in press); an overview of the key ideas are presented here.

Having an adequate grasp of domain knowledge is obviously a prerequisite for being an expert. This represents not only textbook knowledge, but also insights gained from experience in working on real problems. Based on conversations with experts, their knowledge is generally accessed through stories about past cases (Shanteau, 1984). These anecdotal accounts appear to provide both a mnemonic to remember and a convenient way to organize vast amounts of information. As such, they are consistent with efforts to build expert systems through "case-based reasoning" (Kolodner, 1984).

Although knowledge of the domain is necessary, it is not sufficient for expertise. Many novices know a great deal, maybe even as much as experts. In other respects, however, they lack what it takes to behave as an expert.

In previous papers (e.g., Shanteau, 1988), I argued that experts often display a common set of psychological traits. These reflect what Goffman (1959) describes as "self presentation" -- the creation and maintenance of a public image. The traits are part of a decision style found in many experts. These traits include strong self-confidence, excellent communication skills, the ability to adapt to new situations, and a clear sense of responsibility. In short, to be accepted as an expert, it is necessary to act like one.

In prior papers (e.g., Shanteau, 1988), I described various cognitive skills commonly possessed by experts. (Previously, these skills were combined with the psychological traits under the label "psychological characteristics"; I now believe they should be considered separately.) Some of these skills exhibited by experts are highly developed attention abilities, a sense of what is relevant, the ability to identify exceptions to rules, and the capability to work effectively under stress.

My observation of experts also has revealed the use of a variety of formal and informal decision strategies (Shanteau, 1989). These strategies help systematize decision making and have the effect of helping experts overcome cognitive limitations. Although many strategies are unique to given domains, there are several that are widely used. They include making use of dynamic feedback, relying on decision aids, decomposing complex decision problems, and pre-thinking solutions to tough situations.

There is a final factor which is crucial, but often overlooked. The task characteristics determine whether it is possible for experts to behave competently or not. Even with the appropriate knowledge, traits, skills, and strategies, the competence observed in an expert depends on the task. There are some tasks that experts do well, even in the face of considerable difficulty, e.g., weather forecasters (Murphy & Winkler, 1977). In other tasks, experts seem incapable of performing much above the level of novices, e.g., clinical psychologists (Oskamp, 1962). The remainder of this section will be devoted to discussion of task variables.

Task Characteristics

The relationship between domains and decision performance is illustrated in Table 1. The left side of the table lists judgment domains in which competent performance has been reported in the literature. The right side lists domains in which deficient performance has been reported. Except for nurses, physicians, and auditors (listed on both sides),[1] the literature in each field is clear about the level of competence. The question is: What do the tasks on each side have in common?

My original answer (see Table 2) was that domains with competent performance involve static objects or things (Shanteau, 1987b). That is, the experts are being asked to evaluate and make decisions about stimuli that are relatively constant; consequently, judges are faced with a stationary target. Where poor performance is observed, the stimuli are dynamic and generally involve human behavior. Because experts are being asked to evaluate and decide about what is in effect a moving target, they do less well.

Other insights have been offered about this table. Dawes (1987) observed that predictability is different for the two sides: human behavior is inherently less predictable than physical stimuli. Dawes also noted that the competence expected by clients (or the public) varies for the two sides. Clinical psychologists, for example, are expected to be always correct, whereas weather forecasters are allowed to make occasional mistakes. Paradoxically in the less predictable behavioral domains, experts are held to higher standards of performance.

Another difference is that left-side tasks tend to be repetitive -- similar conditions arise from time to time. Right-side tasks, in contrast, are more changeable -- conditions differ frequently. This has implications for the opportunity to receive and respond to feedback. With domains on the left side, there are more chances to learn from past decisions. Based on previous successes and failures, an expert can better his/her decisions. With right-side domains, however, there appear to be fewer chances to learn.

An insightful observation was offered by Gigerenzer (1989), who noted that historically most left-side tasks began as right-side tasks. As understanding of meteorology developed, for example, weather forecasters moved from relying on feelings and guesswork to using detailed climatic information. With the advancement of science, therefore, many unstructured right-side tasks performed by less-competent experts eventually become structured left-side tasks performed by competent experts.

This distinction is supported by the widespread presence of decision aids for left-side tasks (Shanteau, 1989). Sometimes these aids are formal, such as the "soil triangle" used by agronomy judges to define soil classification boundaries (Gaeth & Shanteau, 1984). At other times, the aids are informal, such as the written records kept by livestock judges (Phelps, 1977) to help in learning and to prevent hindsight biases (Fischhoff, 1975). As Edwards and von Winterfeldt (1986) point out, the "unaided expert may be an oxymoron since competent experts will adopt whatever aids are needed to assist their decision making."

In summary, my view is that expert performance is neither uniformly good nor bad. Rather, their competence depends on the task characteristics. The same expert may behave competently in some settings and not in others. That means experts cannot be described generically. Instead, any conclusions must take task into account.

Theoretical Hypotheses

Although the ideas behind the theory are primarily qualitative, it is possible to propose several testable hypotheses. These concern conditions under which experts will or will not make competent decisions. Three hypotheses are described here.

The first hypothesis relates to task characteristics which lead to compe-tent performance. The more a task contains left-side characteristics, the greater the competence that should be seen in experts. Conversely, the more right-side characteristics a task contains, the lesser the competence seen in experts. That means the performance by experts in a given situation should be a function of the number of task characteristics associated with each side.

The second hypothesis involves the <u>decision strategies</u> associated with different tasks. According to the theory, use of left-side strategies, such as problem decomposition with decision aids and feedback, should be greater for left-side tasks. On the other hand, right-side strategies, such as making unaided decisions without use of decomposition or feedback, should be more frequent in right-side tasks. Thus, there should be a direct relation between the strategies used and the type of task.

The final hypothesis involves <u>prescriptive procedures</u> for producing more (or less) competent decisions. Performance in right-side tasks should improve if they can be made more like left-side tasks. This might be done either by changing task characteristics or by encouraging the use of left-side strategies. That means it should be possible to prescriptively improve expert competence, even when there are no objectively verifiable correct answers.

COGNITIVE CONTINUUM THEORY

The left-side, right-side distinction has parallels to Cognitive Continuum Theory (CCT) developed by Hammond (1966) from the ideas of Brunswik (1956). Hammond and Brehmer (1973) define the continuum as follows: "The ANALYTICAL end of the continuum is characterized by a form of thinking that is <u>explicit</u>, <u>sequential</u>, and <u>recoverable</u>. That is, it consists of a series of steps that transform information according to certain rules... (which) can be reported by the thinker.... INTUITIVE thinking, on the other hand, is <u>implicit</u>, <u>nonsequential</u>, and <u>nonrecoverable</u>. Usually, the thinker can report no more than the outcome of his thinking (p. 340)." They go on to define a middle category: "Most instances of thinking will have <u>both</u> intuitive and analytic components. We will refer to this composite as QUASI-RATIONAL thought."

In applying CCT to expertise, Hammond, Hamm, Grassia, and Pearson (1987) identify several cognitive properties that distinguish between intuition and analysis. Intuition is seen as having little cognitive control, rapid processing, and low conscious awareness. In contrast, analysis has high cognitive control, slow processing, and high awareness.

Hammond, et al (1987) distinguish analysis-inducing and intuition-inducing task characteristics. The former includes reliably measured cues, task decomposition, presence of organizing principles, and sequential display of cues. The latter includes unreliably measured cues, nondecomposable task, lack of organizing principles, and simultaneous display of cues.

These task characteristics are consistent with the differences outlined in Table 2. However, the present approach differs from CCT in at least three respects. First, the continuum in CCT represents cognitive style, with analytic and intuitive thinking at the extremes and quasirationality between. In contrast, the theory proposed here has competence and incompetence of expert performance at the two extremes, with no classifiable middle ground. It is unclear how to make the connection between these two continua.

Second, Hammond, et al (1987) argue that accuracy of judgment will be greatest when there is a correspondence between task properties and cognitive properties: "At some point on the cognitive continuum, performance will be best and accuracy will fall off as the expert becomes either more analytic or more intuitive." The present theory, in contrast, is based on a conceptualization of competence that goes from low to high as a function of task characteristics.[2]

Third, CCT is based on a general approach to human judgment applicable to all people, whether expert or naive. The origin of the continuum comes from Brunswik's (1956) analysis of general perceptual processes. In comparison, the present analysis is concerned only with experts and the tasks they perform. It is unclear how to make extensions to naive subjects, since they are incapable of doing or even understanding most expert tasks.

IMPLICATIONS FOR EXPERT SYSTEMS[3]

Using techniques from artificial intelligence, expert systems are increasingly being proposed to aid or even replace skilled decision makers. According to Kolodner (1984), the goal is to build systems which "contain all or most of the compiled knowledge an expert has." Some argue that eventually expert systems will provide "replacements for humans" (Cebrzynski, 1987).

However, getting experts to interact with expert systems has often proved difficult (Michie, 1982). There are several potentially valuable systems, such as MYCIN, that are either unused or misused by the very people the systems were designed to help (Ham, 1984). In other cases, extended efforts to develop expert systems had to be abandoned, in part because of the lack of cooperativeness of experts (Rose, 1988).

At the same time, there has been a debate whether computer systems can mimic experts (e.g., Graubard, 1988). Many investigators see great potential for expert systems (Barrett & Beerel, 1988; Slatter, 1987), although others question whether that potential can ever be realized (Dreyfus & Dreyfus, 1986; Haugeland, 1985).

The analyses of experts here may contribute to a greater understanding of when and where expert systems are likely to be useful. Domain knowledge and experience are clearly necessary for expertise; having the facts and relevant experience are essential for any expert (Naylor, 1987). Nonetheless, knowledge is not sufficient for expertise. By concentrating on knowledge and production rules, other aspects of expertise have been overlooked by builders of expert systems.

I believe the psychological insights described may improve the design, construction, and use of expert systems. The difficult cases are what distinguish experts from those less skilled and the present analyses suggest how competent experts deal with these cases.

Can an expert system be built that incorporates the present approach? Not enough is known yet to answer this question. But the following would, at least, seem necessary to build such a system. First, expertise must be looked at from the perspective of experts, not as something to be defined within the constraints of available hardware and software. Expert systems should reflect the physical and psychological worlds of experts, not the other way around.

Second, experts cannot be expected to explain everything about what they do. Verbal protocols typically are used to capture the information needed to build an expert system. However, at best verbal protocols are inefficient and at worst they may be misleading for representing expertise (Hoffman, 1987). Instead, greater attention should be paid to alternative methods for analyzing experts, such as those used in judgment and decision making research.

Third, more emphasis should be placed on the traits, skills, and strategies of human experts when building computer systems. Traits such as communication ability, skills such as identifying exceptions, and strategies such as dynamic feedback should be incorporated into expert systems. Rigidity is a characteristic of novices (Shanteau, 1989) and most systems, unfortunately, are rigid. Systems should be as flexible as the experts they are designed to simulate.

Lastly, as suggested by Table 1, different types of expert systems may be needed to reflect left-side and right-side expertise. The traditional expert systems may be adequate for the former; these systems generally work best on well-structured problems (Mumpower, Phillips, Renn, & Uppuluri, 1987). However, linear judgment models may be better suited for the latter; the ability of linear approximations to provide good fits to noisy data is well established (Dawes & Corrigan, 1974).

CONCLUDING COMMENTS

Five factors associated with the competence of experts have been identified: domain knowledge, psychological traits, cognitive skills, decision strategies, and task characteristics. The stress here was on the last factor.

The importance of understanding task characteristics has been stressed repeatedly in judgment and decision research (Hammond, et al, 1987). The previous analyses (e.g., Beach, 1990; Howell & Kerkar, 1982; Keller, 1985; Payne, 1982; von Winterfeldt & Edwards, 1986) have focused primarily on contingencies in ongoing decision behavior. As Payne (1982) argues, subjects often invent short-term decision strategies as they go along in an experimental task.

In contrast, the present analysis highlights the connection between task characteristics and asymptotic expert behavior. The competence seen in experts depends on having stable strategies developed in response to their environment. Thus, the concern here is with the long-term instead of short-term influence of task characteristics.

There are many questions remaining to be answered about the effect of task variables on experts. The present research has supplied some tentative answers that hopefully will stimulate further research.

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Table 1. -- Domains in which good (left side) and poor (right side) expert performance have been observed.

Domains with	
Good Performance	Poor Performance
Weather Forecasters	Clinical Psychologists
Livestock Judges	Psychiatrists
Astronomers	Astrologers
Test Pilots	Student Admissions
Soil Judges	Court Judges
Chess Masters	Behavioral Researchers
Physicists	Counselors
Mathematicians	Personnel Selectors
Accountants	Parole Officers
Grain Inspectors	Polygraph (Lie Detector) Judges
Photo Interpreters	Intelligence Analysts
Insurance Analysts	Stock Brokers
Nurses	Nurses
Physicians	Physicians
Auditors	Auditors

Table 2. -- Task characteristics associated with good (left side) and poor (right side) performance in experts.

Characteristics Associated with	
Good Performance	Poor Performance
Static Stimuli	Dynamic (Changeable) Stimuli
Decisions About Things	Decisions About Behavior
Experts Agree on Stimuli	Experts Disagree on Stimuli
More Predictable Problems	Less Predictable Problems
Some Errors Expected	Few Errors Expected
Repetitive Tasks	Unique Tasks
Feedback Available	Feedback Unavailable
Objective Analysis Available	Subjective Analysis Only
Problem Decomposable	Problem Not Decomposable
Decision Aids Common	Decision Aids Rare

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Footnotes

[1] The domains placed on both sides reflect literatures where there is evidence of both competent and less-competent performance. Apparently, the different tasks performed by these experts lead to wide variation in performance level.

[2] As argued in Shanteau (1989), experts often work on tasks that do not have correct answers. For instance, there are no external criteria available to evaluate the quality of decisions made by livestock judges. Nonetheless, livestock judges vary widely in their competence. A similar situation arises for test pilots and grain inspectors.

[3] Much of the material in this section is drawn from the discussion in Shanteau (1989).