Cognition and expertise: acquisition of medical competence

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Abstract

The cognitive study of expertise in knowledge domains has generated a great deal of knowledge that can be used in the education and training of health care providers. This research has looked at the development and characteristics of expert performance. Design of medical and health education systems that are informed by this research can be powerful tools to improve the quality of medical education.

Introduction

The study of cognition has emerged over the past 25 years as the dominant paradigm in psychology and education. Cognitive science is a multidisciplinary field of research, drawing on cognitive psychology, artificial intelligence, cognitive anthropology, philosophy and linguistics. It is primarily concerned with characterizing the knowledge structures and cognitive processes underlying human performance. A major advantage of cognitive research is that we can analyse performance in detail and make specific assumptions about the underlying cognitive processes involved in optimal and suboptimal performance.

Résumé

L’étude cognitive de l’expertise dans des domaines de connaissance a produit beaucoup d’information qui peuvent servir à l’éducation et la formation des prestataires de soins de santé. Dans cette étude, on a examiné le développement et les caractéristiques de la performance des experts. Les systèmes d’éducation en médecine et en santé s’inspirant de ces recherches pourront être des outils puissants pour améliorer la qualité de l’éducation médicale.

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descriptive account of expert performance, in terms of differences in memory, knowledge or skills. For example, studies in medical decision-making have characterized the cognitive and sociocultural factors that enable successful performance. These cognitive factors include efficient use of memory, well-organized knowledge and productive problem-solving strategies.

An expert has attained a high level of standing in his or her domain as exemplified, for example, by board certification in medicine. Research in expertise seeks to understand what distinguishes outstanding individuals in a domain from less outstanding individuals. Several publications have provided excellent overviews of research in expertise. In this paper we attempt to provide an overview of the characteristics of expert performance that are relevant to the acquisition of medical competence.

Knowledge organization and expert performance

It has been repeatedly demonstrated that superior expert performance is mediated by highly structured and richly interconnected domain-specific knowledge. Human cognition is constrained by the limitations of working memory. Experts’ well-organized domain knowledge enables them to circumvent some of these limitations. For instance, expert chess players were able to reconstruct from memory mid-game chess positions of 24 to 25 pieces, whereas novices players were only able to reconstruct 4 to 5 pieces. However, when the chess board layout was randomized, experts were not able to perform any better than novices. This demonstrates that performance is not a result of generally superior memory skills. Rather, it is a function of a well-organized knowledge base adapted to recognize familiar configurations of stimuli.

The nature of experts’ knowledge can also account for their superior perceptions of patterns. This is compellingly demonstrated in studies of expert radiologists. Experts were able to rapidly generate a coherent representation of an x-ray film, differentiate pathologic conditions from film anomalies (e.g., shadows) and effectively use clinical information to update their representations and narrow the space of diagnostic possibilities.

Experts’ superior performance can be explained as the result of the comprehensiveness and organization of their knowledge base. First, it has been estimated that the number of familiar chunks of game-related information in a chess master’s long-term memory is approximately 50,000. Roughly the same number of chunks of information seem to be required for expertise in many domains (e.g., medicine, mathematics, chemistry), and about 10 years of devoted effort seems to be required to accumulate this large a store of information in a discipline. Second, experts’ knowledge bases are hierarchical and densely interconnected, which allows new pieces of information to become well integrated. For example, expert cardiologists are routinely called upon to integrate clinical findings at various levels of aggregation, from biochemical abnormalities evidenced in blood tests to perturbations at the system level to clinical manifestations as expressed in the patient’s complaints.

As practitioners gain experience in the execution of a task, their performance becomes increasingly smooth, efficient and automatic. While developing proficiency with attention-demanding complex tasks, some component skills become automatic, so that conscious processing can be devoted to reasoning and reflective thought with minimal interference in the overall performance. A great deal of experts’ knowledge is finely tuned and highly automated, enabling them to execute a set of procedures in an efficient, yet highly adaptive manner, which is sensitive to shifting contexts.

The development of adaptive expertise

It was widely believed that the development of expertise is characterized by a cumulative and regular improvement in knowledge and skills, which culminates in the optimal performance of the expert. However, the acquisition of expertise is characterized by a developmental pattern in which periods of smooth incremental learning may be followed by periods of consolidation of knowledge that may cause a decline in performance. This phenomenon is known as the “intermediate effect.” The intermediate effect occurs at various levels of expertise and with tasks varying from comprehension of clinical cases and explanation of clinical problems to problem-solving.
The common finding is that intermediate performance involves extraneous search and effort. For example, intermediates recall detailed information, provide unnecessary elaborations in explaining patient problems,\textsuperscript{11,12} elicit considerable amounts of information from a patient to make a diagnosis or request many extraneous laboratory tests.\textsuperscript{13}

The pattern of development may be explained by the fact that intermediates have acquired an extensive body of knowledge but have not yet reorganized this knowledge in a functional manner. Experts’ knowledge is finely tuned to perform various tasks, and they can readily filter out irrelevant information. Novices, on the other hand, do not conduct irrelevant searches, simply because they lack knowledge rich enough to search. Whereas a novice’s knowledge base is sparse and an expert’s knowledge base is intricately interconnected, an intermediate may have a lot of the pieces of knowledge in place but lack the extensive connectedness of an expert. Until this knowledge becomes further consolidated, the intermediate is more likely to engage in unnecessary search. The intermediate effect is not a one-time phenomenon, rather it occurs repeatedly at strategic points in a student’s or physician’s training that follow periods in which large bodies of new knowledge or complex skills are acquired. These periods are followed by intervals in which there is a decrement in performance until a new level of mastery is achieved.

Education has to foster ways of learning that promote self-regulation and adaptability. Through their extensive experience, experts develop a critical set of self-regulatory or “metacognitive” skills, which controls their performance and allows them to adapt to changing situations. For example, experts monitor their problem-solving by predicting the difficulty of problems, allocating time appropriately, noting their errors or failure to comprehend and checking questionable solutions. Novices are less understanding of task demands and how these match their capabilities, and this prevents them from tackling problems strategically. When they reach an intermediate stage in learning, they give more signs of self-regulation: they plan steps effortfully and explicitly before executing them and evaluate them afterward. By the time they become experts, these self-regulating skills will be so well practised that they are effortless.

A goal of medical education should be to promote the acquisition of self-regulated learning. To achieve such a goal, the educational system has to foster changes in the agency of learning.\textsuperscript{14} Initially, learning involves a significant degree of external support, through early environmental structuring (especially for novices, such as beginning medical students). However, as competence is attained, there is an increasing amount of internalized self-regulation, when there is a transition period involving decreasing scaffolding of environmental support and an increasing opportunity through guided apprenticeship (intermediates). As the direct external support fades away, learning occurs increasingly under the control of the learner.

**Toward cognitive theories that support education**

Cognitive researchers, having spent a great deal of effort in characterizing the nature of expertise, have shifted their attention to research on learning and instruction. In particular, there has been considerable research on engineering classrooms and computer-based learning environments based on emerging cognitive principles of learning and instruction. The current state of affairs has resulted, not in a cohesive unified learning theory but rather in a family of such theories. Medicine is a complex multifaceted knowledge-rich domain encompassing a range of performance skills and knowledge domains. Clearly, it is not likely that any one theory or approach to learning and pedagogy will adequately capture it in all its complexity.

There are 3 major components to a theory of learning and instruction,\textsuperscript{15–17} a theory of competent, skilled, knowledgeable performance as exemplified by domain experts; an acquisition theory concerning the process of learning and development; and a theory of intervention describing methods for enhancing teaching and learning. Although most progress has been made in the characterization of competent performance, significant strides are being made in the development of theories and methods regarding the acquisition of knowledge and skills, and cognitive instructional approaches to education. The research has identified several forms of learning, such as the
following: learning by doing, which focus on individual learning through practice, with an emphasis on procedural skills; conceptual change, which involves the learning in understanding biomedical concepts; apprenticeship learning, which is guided learning through a process of mentorship in a practice setting; collaborative learning, in which the emphasis is on learning through a process of interactive discourse and participation in activities; and case-based learning, in which the emphasis is on learning through exposure to a variety of cases or problems. Each type of learning requires distinct kinds of pedagogical and practical experience.

Given that practice is central to learning in the professions, there has been much emphasis on the situated character of knowledge and skill. Some researchers have argued against the assumption that conceptual knowledge can be abstracted from a situation in which it is learned to a situation in which it is used. Students routinely acquire knowledge without having the ability to use it in a meaningful context. These researchers stress the need for participation in authentic activity and to observe practitioners “wrestling with problems of the world.” Through a process of enculturation, learners become involved in a community of practitioners and increasingly assume the role and identity of full participants. Medical students and trainees become enculturated into the world of medical practitioners through an extended apprenticeship process. Much of the practice of medicine is collaborative in nature, and cognition in the workplace is shaped by the social context as well as the technologic and other artifacts that are embedded in the physical setting.

In medicine, the attainment of expert-level performance in the workplace is predicated on the subjects’ ability to function smoothly in an environment in which the coordination of tasks, decisions and information is essential. In complex dynamic decision-making environments, the situational and distributed aspects of expertise are emphasized — such as communication capabilities, the ability to convey plans and intentions, and the allocation of resources not only for one’s self, but for others. Learning in such circumstances necessitates the development of pattern recognition capabilities that lead to rapid heuristically guided decisions under conditions of uncertainty and incomplete information. It also necessitates a complex sociocognitive coordination process in which information-gathering, decision-making and patient management are highly interactive and distributed activities.

Research on medical expertise is beginning to inform the development of medical education in real world settings. Although the expert characteristics described in this paper can suggest changes to the way medical education is conducted, we still need to understand more about the conditions of learning that lead to more optimal levels of performance. Emerging computer technologies, if used judiciously, can play an important role in the process of medical education. Much as biomedical science has revolutionized health care practice, social and cognitive research can provide a scientific foundation for education in medicine and health.

References


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