How expertise develops in medicine: knowledge encapsulation and illness script formation

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CONTEXT For over 30 years, research has focused on the question of how knowledge is organised in the doctor's mind. The development of encapsulated knowledge, followed by the formation of illness scripts, may both be considered as important stages in the development of medical expertise.

METHODS This paper reviews research on the knowledge encapsulation and illness script hypotheses since their initial formulation. Findings in support of these views of expertise development are reported and conflicting data are discussed.

RESULTS A great deal of empirical data have been collected over the years to investigate the view that, through clinical experiences, biomedical knowledge becomes encapsulated and eventually integrated into illness scripts. The findings of most studies, which have used various techniques to probe the ways by which students and doctors mentally represent clinical cases, are in line with this view of expertise development. However, there is still debate concerning the role of biomedical knowledge in clinical case processing.

CONCLUSIONS To facilitate the development of expertise in medical school, it is important to teach the basic sciences in a clinical context, and to introduce patient problems early in the curriculum in order to support the processes of encapsulation and illness script formation. In addition, during clerkships ample time should be devoted to enabling reflection on patient problems with peers and expert doctors.

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KEYWORDS *clinical competence; *problem solving; clinical clerkship/*methods; curriculum; group processes; peer group; teaching/*methods.

*Medical Education 2007: **41**: 1133–1139*
doi:10.1111/j.1365-2923.2007.02915.x

INTRODUCTION

Since the early 1970s, several attempts have been made to formulate a theory of medical expertise that would provide a parsimonious account for the available data on how expert doctors deal with medical problems. These attempts can be characterised as either 'processing' or 'structure' theories. Processing theories seek expertise in the particular ways in which doctors *process* patient-relevant information. The best-known theory in this category is the approach of Elstein *et al.*[1] They postulated that medical experts deal with patient information through a cognitive process called hypothetico-deduction, where an expert would generate hypotheses early in the encounter with a patient and would test these hypotheses against data gathered in context. (For a critique of this theory, see Patel and Groen;[2] for a rebuttal, see Norman *et al.*[3]) Structure theories, by contrast, focus on the *underlying knowledge structures* that produce diagnostic hypotheses. Lesgold *et al.*,[4] for instance, suggested that diagnostic accuracy is mainly determined by the extent to which the expert possesses rich causal biomedical knowledge structures in memory.

Our own attempts to contribute to the field within the structure paradigm concentrated on how expertise in medicine matures: how do medical students actually develop medical expertise in the course of medical education? To that end we proposed a theory that considers the development of expertise as progressing through a number of transitory stages,

Overview

What is already known on this subject

The development of medical expertise is a process in which different stages can be identified. The emergence of encapsulated knowledge and rich illness scripts can be considered as defining characteristics of expertise development.

What this study adds

This study provides an integrative and critical overview of more than 20 years of research on knowledge encapsulation and illness scripts. Implications for teaching are discussed.

Suggestions for further research

Recent non-experimental studies suggest that biomedical knowledge plays a more prominent role in professional practice than had been assumed earlier. There is a need for experimental studies that further investigate its role.

each characterised by knowledge structures underlying diagnostic performance that are qualitatively different from those of other stages.[5–7] The purpose of the present paper is to summarise the research conducted within this framework since its initial formulation. In view of the available space, we will concentrate on research that specifically focused on our theory. This is not to say that research by other investigators in the field did not contribute to our particular point of view. In particular, the contributions of Patel and Groen[2] and Norman *et al.*[8] have been inspirational. First, we will sketch our theory.

TRANSITORY STAGES IN EXPERTISE DEVELOPMENT

Most early cognitive theories of expertise development[9] consider it to be largely a process of the extension of causal knowledge about a domain. Through education and experience, students acquire more and more relevant concepts and develop richer and more meaningful relationships between them. In other words, expertise development is largely a matter of knowledge *expansion*. The theory outlined here deviates from these proposals in that it postulates that the development of expertise in medicine can only be properly understood by assuming certain kinds of knowledge shifts or knowledge *restructuring* in the course of growth towards expertise. In this section, therefore, the development of medical expertise involving this idea of distinct stages or 'phases' will be briefly outlined.

Our position as to how expertise in medicine develops can be summarised as follows: in the course of their early medical training, students rapidly develop mental structures that can be described as rich, elaborate *causal networks* that explain the causes and consequences of disease in terms of general underlying biological or pathophysiological processes. When confronted with a clinical case in this stage of development, students focus on isolated signs and symptoms and attempt to relate each of these to the pathophysiological concepts they have learned. This is an effortful and error-prone process. In addition, as they do not yet recognise patterns of symptoms that fit together, processing is detailed. This is why intermediate-level students remember more details of such cases than medical experts, provided they have enough time to do so; this results in an *intermediate* effect in clinical case recall.[10,11] (With hindsight, this seems pretty obvious. However, before the discovery of intermediate effects in case recall, there was general agreement among researchers – and empirical evidence from domains such as chess – that experts would recall more information than novices and intermediates because they have more appropriate knowledge available with which to interpret and, hence, retain the information.) In addition, when asked to think aloud while solving a clinical case, intermediate-level students tend to use detailed knowledge of the basic sciences (e.g. physiology, biochemistry, anatomy) in explaining for themselves the signs and symptoms of the patient. These references to the basic sciences are virtually absent in the think-aloud protocols of expert doctors.[12,13]

However, through extensive and repeated application of knowledge acquired and, particularly, through exposure to patient problems, a change in the knowledge structures of these students occurs. Their networks of detailed, causal, pathophysiological knowledge become *encapsulated* into diagnostic labels or high-level, simplified causal models that explain signs and symptoms. Knowledge encapsulation is a learning mechanism that can be defined as the subsuming or 'packaging' of lower-level, detailed concepts and their inter-relations, under a smaller number of higher-level concepts with the same explanatory power.[5] An example may clarify what is meant by encapsulation. Assume that a young man who is suspected to be an intravenous drug addict enters the emergency room. He complains of shaking chills and fever. The fever and chills are accompanied by sweating, and a feeling of prostration. He also complains of some shortness of breath when he tries to climb the 2 flights of stairs to his apartment. Physical examination reveals a toxic looking young man who is having a rigor. His temperature is 41°C. His pulse is 124/minute. His blood pressure is 110/40. Mucous membranes are clear. Examination of his limbs shows puncture wounds in his left antecubital fossa.[2] A Year 6 medical student, when asked to explain these symptoms, would say this:

> 'This man must have been using contaminated needles, which led to an infection with gram-negative bacteria. These bacteria in the bloodstream lead to the activation of antibodies, which explains the fever reaction: the high temperature, the shaking chills, the sweating, the feeling of prostration, and the shortness of breath. The bacteria also release endotoxins, leading to vasodilatation of the arteries. Vasodilatation in turn leads to the observed drop in blood pressure and possibly shock. Decreased resistance may be a reason why the immune response fails…'

An internist, by contrast, would respond this way:

> 'This drugs user has developed a *sepsis* as a result of using contaminated needles.'

The concept of sepsis is sufficient to explain all relevant signs and symptoms; it encapsulates, or stands for, the student's detailed pathophysiological explanation. This implies that in response to such a case the expert would no longer activate knowledge of the behaviour of the bacteria and the reaction of the body; activation of the single concept of sepsis is sufficient to fully explain the condition of the patient. It may be clear that having available a concept such as sepsis enables one to see patterns of symptoms as wholes, and that the availability of this concept considerably speeds up the processing of a case and contributes to accurate diagnosis. Experts have many encapsulating concepts available, describing syndromes (i.e. groups of symptoms that collectively indicate or characterise a disease) or simplified causal mechanisms. This knowledge is often called clinical knowledge (as opposed to biomedical knowledge) and experts tend to use this kind of knowledge preferentially. This is why the think-aloud protocols of experts, unlike the protocols of students, feature hardly any basic science concepts;[12,13] experts simply have more efficient instruments for understanding available.

As students begin to practise extensively with actual patients, a second shift occurs. Their encapsulated knowledge is reorganised into the type of narrative structures we referred to as illness scripts, following Feltovich and Barrows.[14] These illness scripts are cognitive entities containing relatively little knowledge about pathophysiological causes of symptoms and complaints (because of encapsulation), but a wealth of clinically relevant information about the *enabling conditions of disease*, as a product of growing experience with how disease manifests itself in daily life. Possessing knowledge about enabling conditions is supposed to characterise advanced levels of expertise because it enables the doctor to rule out whole categories of disease and to focus immediately on those that are most likely. For instance, if, in the middle of an influenza epidemic, a woman enters the consulting room complaining of fever-like symptoms, the doctor might think of influenza. However, if she professes that she has recently been in a malaria-infested region of the world, then alternative hypotheses suddenly become more relevant. Thus, 'having been to Africa recently' is knowledge that can add considerably to the accuracy of diagnoses and to the speed with which decisions can be made, despite the fact that the knowledge is enabling rather than causal. The acquisition of enabling-conditions knowledge is largely based on practical experience; education seems to play a lesser role.[15]

Illness scripts exist at various levels of generality, ranging from representations of disease categories to prototypes, to representations of individual patients seen before. Indeed, a salient feature of our theory is the assumption that doctors sometimes actually use memories of previous patients when diagnosing a new case.[16,17] Thus, while solving a problem, a doctor searches for an appropriate script and when he has selected 1 (or a few), he will tend to match its elements to the information provided by the patient. In the course of this script verification process, the script becomes *instantiated*. Instantiated scripts in turn, do not necessarily become decontextualised after use but remain available in memory as episodic traces of previously analysed patients and may be used in the diagnosis of similar problems in the future.

Table 1 contains a summary of our conjectures.

Table 1 Transitory stages in the development of medical expertise

1 Development of elaborate declarative networks explaining the causes and consequences of disease in terms of general underlying pathophysiological processes
2 'Encapsulation' of these declarative networks into a limited number of diagnostic labels, syndromes or high-level, simplified causal models, explaining signs and symptoms
3 Transition into 'illness scripts' through the acquisition of experience-based, contextual or 'enabling conditions' knowledge
4 Storage of interpreted instances of these scripts as exemplars of the particular illness

SUMMARY OF RESEARCH

The encapsulation hypothesis

Several of the predictions derived from the idea that biomedical knowledge becomes encapsulated into clinical concepts have been confirmed. Encapsulated knowledge is more readily assessed by doctors than biomedical knowledge.[18] Pathophysiological explanations by experts contain less biomedical and more encapsulating concepts than those by students of different levels.[19] The recall protocols of experts contain more encapsulations than those of subexperts (i.e. experts recalling cases outside their specific specialties).[20] Moreover, biomedical knowledge is only indirectly related to clinical competence.[21] Of particular interest is the work of Woods *et al.* on the role of causal knowledge in diagnosis.[22,23] They asked students either to learn a list of features associated with a number of diseases, or to learn causal, biomedical knowledge associated with these diseases. Although initially both groups performed similarly well on a diagnostic task, students from the causal condition did better after a delay of 1 week, suggesting that causal knowledge clarifies coherence among symptoms in a way that simple associative knowledge does not. More importantly, the authors demonstrated that students spontaneously develop encapsulations, as evidenced by better performance on a recognition test presenting *new* concepts encapsulating the causal mechanisms learned.[22,23] The availability of these concepts seemed to facilitate processing speed,[24] as predicted by the encapsulation hypothesis. Finally, intermediate effects were shown in the recall of electrocardiogram traces,[25] breast cancer cases,[26] psychodiagnostic classification,[27] and even non-medical texts.[28]

Initial critiques of the encapsulation hypothesis[29] suggested that the intermediate effect might be an artefact of the procedure used: doctors actually remember more from a case, but, for various reasons, do not demonstrate their superiority in free recall. Eva *et al.*,[30] however, showed that the effect also occurs in *recognition* of patient data: intermediates actually recognise more of the patient information in a case than experts. Another early appraisal suggested that the intermediate effect only occurs when the primary task is to diagnose the case. If experts are asked to remember the case rather than to diagnose, they do better.[8] The intermediate effect has turned out to be, however, quite robust against experimental manipulations. In a series of experiments Van de Wiel[31] demonstrated that neither experimental instructions (to diagnose a case, to recall a case), nor case characteristics (laboratory test data presented in summary form or in full) influenced the magnitude of the intermediate effect. De Bruin *et al.*[32] tricked half their experts into believing that national experts would evaluate the quality of their recall protocols. However, this manipulation did not influence the amount and nature of case recall.

Two studies have yielded expertise effects in case recall rather than intermediate effects. In 1 of them, Norman *et al.*[8] asked students and nephrologists to diagnose and recall cases solely consisting of laboratory findings. The nephrologists' recall was much better than the recall of the advanced students. A first attempt to explain this anomaly failed; Verkoeijen *et al.*[33] presented the same cases with and without a clinical context to internists and students. Both conditions produced an intermediate effect in recall. Closer scrutiny of the procedure followed by Norman *et al.* revealed that they had asked their participants while processing the case to comment on each laboratory result in the light of hypotheses entertained. Wimmers *et al.*[34] repeated this procedure, asking nephrologists to elaborate on the cases, and replicated Norman *et al.*'s findings. A control condition in which the nephrologists processed the cases without elaboration revealed an intermediate effect again. This study and Norman *et al.*'s earlier study show that only if you oblige experts to process a case elaborately and deliberately, focusing on detail, will they produce better recall than intermediates. This is, however, not their natural way of approaching the diagnostic task. Under normal conditions, processing is characterised by the use of encapsulating concepts that lead to remembering only the most critical signs and symptoms. A second study demonstrating expertise effects in recall remains unexplained.[35]

Van de Wiel *et al.*[36] tested the assumption that clinicians' biomedical knowledge does not disintegrate or decay over time. Our theory states that basic science knowledge must remain available for activation when a case turns out to be difficult. The authors asked doctors, clerks and advanced students to explain 20 clinical constructs in terms of underlying pathophysiology. The resulting protocols of the doctors displayed generally more elaborate, qualitatively better, and more fluent explanations than those of the clerks and students. Pathophysiological knowledge relating to the causes and consequences of disease does not decay with experience, but, rather, forms a coherent structure of knowledge that can be easily accessed when needed. This is in line with findings from a study by Patel *et al.*,[37] which showed that when experts were confronted with a difficult case, the number of biomedical concepts in their protocols increased. It is also in line with findings from research employing (lexical) decision tasks, which demonstrate that experts have biomedical knowledge that is easily accessible when needed.[38,39]

The illness script hypothesis

We assumed that advanced expertise would be characterised by the emergence of illness scripts, rich in terms of enabling conditions knowledge. Several studies have demonstrated that the number of enabling conditions associated with particular diseases increases with expertise.[40–42] For instance, when study subjects were asked to describe the clinical picture of a set of diseases, the number of enabling conditions mentioned increased as the level of respondent expertise rose. In addition, a positive relation was found between the number of actual patients seen with a particular disease and the number of enabling conditions mentioned.[40] Another study demonstrated that expert performance was sensitive to typicality of both enabling conditions and consequences, whereas advanced students' performance was sensitive only to typicality of consequences.[41] Van Schaik *et al.*[42] studied the influence of enabling conditions on general practitioners' referral behaviour for gastrointestinal disorders. Levels of experience interacted with the use of enabling conditions: the more experienced they were, the more the doctors would use enabling condition information in the cases. However, contrary to illness script theory, evidence was also found for moderation of consequences.

These studies seem to imply that, with growing expertise, the number and richness of enabling conditions increases and experienced doctors make increasing use of knowledge of enabling conditions.

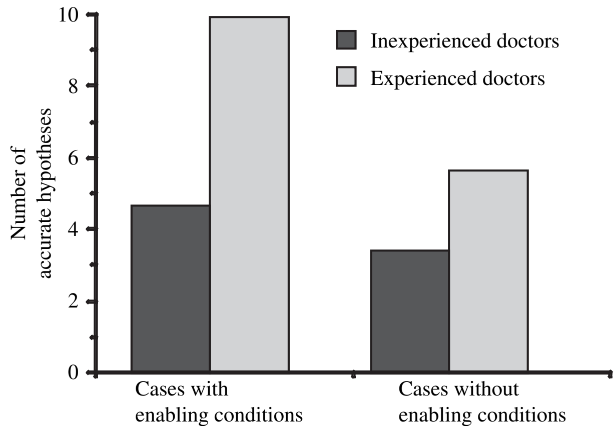

Figure 1 Influence of the availability of enabling conditions on the diagnostic performance of relatively inexperienced and experienced general practitioners. Adapted from Hobus[15]

The experts' dependence on enabling conditions for diagnosis is best exemplified by a study by Hobus.[15] He presented 16 short cases consisting solely of a number of enabling conditions and a single presenting complaint. Experienced doctors were almost twice as good as inexperienced doctors at diagnosing these cases. However, when these cases were presented without enabling conditions in a second experiment, the differences in diagnostic accuracy between experienced and inexperienced doctors disappeared entirely, demonstrating that advanced expertise in a domain seems to be solely dependent on the acquisition of enabling conditions through extended practice. Fig. 1 summarises the Hobus findings.

DISCUSSION

Many studies conducted within the encapsulation–illness script paradigm seem to support its predictions. In particular, the crucial role of knowledge of enabling conditions in advanced levels of medical expertise, and the fact that this knowledge is experiential rather than taught, seems to be well established. By contrast, the seemingly conflicting findings indicate that the extent to which experts actually use biomedical knowledge in their dealings with patients remains a thorny issue in need of further clarification. In particular, studies by Van de Wiel *et al.*[36] and Rikers *et al.*[18,39] demonstrate, contrary to predictions of the encapsulation hypothesis, that experts are actually better or faster at using biomedical knowledge than advanced students. This suggests that biomedical knowledge must be more frequently used in professional practice than assumed earlier. However, as many of these studies used non-experimental designs, alternative explanations could not always be ruled out. There is a definite need for more experimental studies here.

What are the implications of these findings for the practice of medical education? We mention 3 here.

1 Basic science should be taught only to the extent that it is – directly or indirectly – relevant to the development of encapsulating concepts. The integration of biomedical and clinical science should not be left to the students but the encapsulation process should be supported by *integrated teaching*. We firmly believe that modern curricula emphasising the organisation of disease processes around organ systems are more effective than the classic Flexnerian curriculum, which emphasises the teaching of biomedical and clinical knowledge as different phases in the medical curriculum.

2 Allow students to work with patient problems early in the curriculum, and allow them to see many and varied patients. This would certainly encourage processes of encapsulation and illness script formation. In this respect many curricula fall short. For instance, Wimmers *et al.*[43] found that, during a 12-week internal medicine clerkship, students saw fewer than 4 patients on average each week and, in fact, were confronted with little more than a single different disease per week. Thus, such clerkships can hardly be considered to contribute to the growth of expertise in these students.

3 Much time during clerkships and other postings should be spent on having students reflect and elaborate on the problems of the patients they see. Elaboration with a coach, preferably in small groups of peers, is generally considered a most effective way to integrate knowledge from different sources and to develop knowledge structures fit to the task at hand.[44,45]

Contributors: both authors discussed the ideas outlined in this paper. The first author wrote the first draft of the paper. The second author contributed parts of the final text.
Acknowledgements: none.
Funding: none.
Conflicts of interest: none.
Ethical approval: not applicable.

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Received 21 May 2007; accepted for publication 1 August 2007