Chapter 3

Medical expertise and its development

3.1 Introduction

This chapter addresses the question of what characterizes the expertise of a medical professional. This we do with the goal of identifying the elements of the expertise that should be modelled in a medical diagnostic support system.

In the literature, we have found two lines of research that are rather relevant for our research. These are research on expertise in clinical reasoning which analyses the cognitive processes of clinical reasoning, and instructional research dealing with the development of new medical curricula.

The first of these is concerned with understanding the nature of clinical reasoning, while the second deals with the issues related to teaching of clinical reasoning. Both of these research subjects have usually been investigated via studying the differences between experts and novices. Remarkable differences have been observed between experts and novices with respect to efficiency and quality concerns.

What is prerequisite to expertise? This question has been investigated via both a process and content orientation [Higgs 95], emphasizing respectively the behaviours and the cognition, and the clinical knowledge. The distinction between content and process has been summarized by Barrows and Pickell as follows: “There are two components of an expert clinical problem-solving that need to be considered separately even though they cannot be separated in practice. One is content, the rich extensive knowledge base about medicine that resides in the long term memory of the expert. The other is the process, the method of knowledge manipulation the expert uses to apply that knowledge to the patient’s problem. In expert performance these components are inexorably intertwined. Both are required; a well developed reasoning process appropriately bringing accurate knowledge to bear on a problem in the most effective manner.”([Barrows 91], p. xii).

The very first attempts to analyse clinical expertise took as basis the performance of the professionals. This was at the same time as behaviorism was the leading paradigm in psychology. Later, with the rise of cognitive psychology, the emphasis from behavior shifted to the general cognitive processes underlying clinical problem solving. Before 1980, the essence of medical expertise had been explained in terms of variables such as quality of problem solving processes, efficiency, and number of hypotheses considered ([Custers 96]; [Bordage 91]. The seminal work of Elstein [Elstein 78] presented the first model of medical reasoning suggesting no difference between the strategies applied by novices and experts in medical domain; both use general strategies. This was at the same time as that Newell and Simon investigated general problem solving methods. Their aim was to invent weak methods which could be applicable across many domains irrespective of the domain specific knowledge. This presupposed a distinction between disease knowledge and the reasoning process, as also is exemplified in expert system implementations [Clancey 84].
The distinction between the process and knowledge used in clinical problem solving has had an important impact on instructional research. Since the early process-oriented research claimed that both novices and experts apply general strategies, instructional research stressed the role of teaching general problem solving strategies.

The later research on clinical reasoning anticipated that novices and experts use different problem solving strategies. Experts use strategies that rely on the knowledge base in order to limit the search. According to [Patel 86] experts apply a pattern recognition strategy relying on the rich and structured content knowledge. This approach triggered a content-oriented approach to medical reasoning.

Instead of investigating general strategies, investigations have been initiated in order to find out whether the organization and availability of domain specific knowledge could be responsible for ‘good’ medical reasoning [Feltovich 84; Bordage 84; Patel 86; Barrows 87]. The idea was to show that efficient problem solving is conditioned on exclusive and well organized knowledge about the problem domain. The findings have rendered knowledge organization as an important underlying reason for an expert’s diagnostic superiority. The content-oriented approach originated from the idea that “A very intelligent person might be that way because of specific local features of his knowledge organizing rather than because of global qualities of his thinking”.

More recent trends, however stress an interdependence between clinical reasoning process and clinical knowledge [Norman 90; Schmidt 90; Boshuizen 91; Patel 90; Arocha 93] which is gaining increased acceptance. In this view, the use of different processes by experts and novices was explained in key terms of ‘experience’ of the clinician, and the ‘difficulty degree’ of the problem [Patel 90; Schmidt 90; Boshuizen 91]. As the interpretations of what the differences are between experts and novices changed, the approaches to the development of expertise also has changed. The reflection of this approach on instructional research suggests a focus on the integration of content and process. The ‘problem based learning’ (PBL) curricula presuppose that learning can be facilitated if the learning happens in the real world context in which the students need to apply what they have learned. This argument agrees perfectly with Tulving’s ‘encoding specificity’ theory since it also stresses the importance of the correspondance in the context at learning and remembering time. We elaborate encoding specificity theory in chapter 8.

We will, following Higgs [Higgs 95], identify four main approaches to medical problem solving in the literature; the hypothetico-deductive model, the pattern recognition model, the knowledge-reasoning integration model, and the holistic model. The first two investigate the process of the clinical reasoning. The pattern recognition model recognizes the role of knowledge content, while the hypothetico-deductive model completely ignores it. The last two models emphasize the importance of both process and the content. They focus on the integration of the content and the process. The holistic approach, in addition, stresses the role of context in clinical reasoning. These four approaches are presented in the following sections.

---

1. By knowledge organisation we will understand knowledge content including its structure.

2. Due to Minsky and Papert (1974), referred to in [Glaser 88]]
3.2 The “hypothetico-deductive” model

The seminal work of Elstein et. al. [Elstein 78] contrasted the medical problem solving of experts and novices, in terms of the cognitive processes employed by these two groups. Elstein et. al. attempted to identify the strategies and processes that distinguished experts from less experts. They postulated that a crucial difference between experts and novices was that experts employed different processes than novices. However, Elstein et. al., contrary to their expectations, did not find significant differences between the processes used by experts and novices; both used, in their terms, a hypothetico-deductive method. Other medical researchers also portrayed hypothetico-deductive reasoning as a model of clinical reasoning [Kassirer 78; Feltovich 84b]. This approach involves generation of a limited number of hypotheses based on clinical data and information, and testing of the hypotheses through further on-going inquiry. The generation stage is called an induction\textsuperscript{1} process while the testing part is called a deductive process. [Barrows 91] interprets this ‘inductive’ stage as a way of structuring or understanding the problem. It is this understanding that governs further reasoning. Hypothesis generation occurs rather early, and is a rapid and automatic process. That is, clinicians from all levels of expertise generate, early in the workup, a set of hypotheses. In the testing stage, these hypotheses are used to predict what additional findings should be present if the hypothesis is true.

According to Higgs, the hypothetico-deductive approach ignored the fact that knowledge of the problem solver could provide a significant source with respect to differences between experts and novices. This implies a lack of consideration whether “effective problem solving requires a large store of relevant knowledge” [Higgs 95], p. 9).

The early findings of Elstein et. al. were, in fact, calling for another research agenda. This is because even though they did not detect any difference between experts and novices with respect to ‘process’, they found other differences. These are;

1) Difference in the quality of hypotheses: An important finding of Elstein was the observation of differences in the content of the generated hypotheses set. The experts were superior to generate more correct hypotheses even in the first generation round. So, there is a prominent difference between novices and experts; even though they both used a hypothetico-deductive method, they generated different sets of hypothesis for the same patient case.

2) Difference across cases: Elstein [Elstein 78] also found that problem solving expertise varies greatly across cases and is highly dependent of a clinician’s mastery in the particular area. However, these findings have not been further investigated neither by Elstein himself nor by cognitive psychologists, as cognitive psychology focused on the role of process rather than that of knowledge at that time. As we mentioned above, the dominating research subject was the general strategies and skills. As such, the role of experience had been underrated. Consequently, the role of experience, its influences on organization

\textsuperscript{1}. Along these lines, we will use the term ‘abduction’ instead of ‘induction’ in later chapters. The reasons for preferring this term is explained in chapters 4, 5, and 6.
of knowledge, and its effects, in turn, on the diagnostic process had to wait for being investigated until a shift occurred in the focus of cognitive psychology.

After this shift, however, the generality of the hypothetico-deductive method has been subject to prominent critique by cognitive psychologists who suggest that clinical reasoning may sometimes be a pattern recognition process [Patel 86], rather than a purely hypothetico-deductive process. This approach is elaborated in the next section.

3.3 The “pattern recognition” model

Patel (Patel 86; Patel 90), challenging Elstein’s hypothetico-deductive model, suggested that experts and novices may not be using the same reasoning process. Experts use a “pattern recognition” model, rather than a hypothetico-deductive method.

In this view, the process used by experts is primarily an inductive process, a forward reasoning, and is essentially a kind of pattern recognition. Forward reasoning is data driven and occurs when cues available about the patient are utilized in order to evoke diagnostic hypotheses while backward reasoning is hypothesis driven. According to Patel, medical experts do not display explicit hypothesis testing in familiar situations.

The relationship between the level of expertise and the directionality of reasoning has been investigated through a series of experiments. According to the early findings suggested by Patel’s work [Patel 86], expert cardiologists who established accurate diagnoses always used pure forward reasoning, while novices uses most backward reasoning. However, later investigations [Patel 90] showed that experts also use backward reasoning but only when the available cues used for pattern recognition are not sufficient to arrive at a solution. Hence, experts fall back on backward reasoning when confronted with “loose ends”, that is, unrelated facts. The expert ability to use forward reasoning has been attributed to the possession of highly organized knowledge of the underlying cardiac disorder.

The “pattern recognition” model of clinical reasoning is a “forward” process [Patel 86] and is based on the presupposition of existence of some knowledge patterns in the memory of the clinician which could be recalled by using the cues available in the new patient situation. Thus, this account emphasizes the role of content in the choice of strategy to be employed in clinical problem solving.

Higgs explains pattern reasoning as including categorization and prototypes. “Categorization involves grouping of objects or events. It can be related to the process of recognizing the similarity between a set of signs and symptoms and a previously experienced clinical pattern or case. The new case is placed in the same category as the past case(s) and is given the same label (diagnosis)” ([Higgs 95], p.13)

The whole theory originates from the idea that experts have a knowledge base with a richer content than that of novices. Further, they have an adequately organised and structured memory, a characteristic which novices lack. This is what make experts able to use a faster and more efficient inductive process. This happens when the case is a familiar, routine case. Other results from Patel’s group revealed that clinicians use a combination of forward and backward reasoning when encountering unfamiliar, difficult problems with incomplete or inaccurate data and information. This supports also Chi’s argument that whether a child uses a particular strategy is highly dependent of her knowledge base.
In the following section we present a different interpretation of the relationship between induction, forward reasoning, and pattern recognition. This is a move toward a more global view of diagnostic reasoning which combines hypothetico-deductive and pattern-recognition models into one model.

### 3.4 The relationship between the hypothetico-deductive and the pattern-recognition models

An aspect which has been less explicat ed in both the hypothetico-deductive and pattern recognition models is that both require a “hypotheses evoking” process. However, depending on the richness of the experience and the structure of the knowledge base, the methods to evoke hypotheses may be different in experts and novices. Obviously, the method to be used for selection of the one to be tested may differ in novices and experts. So, the difference between hypothetico-deductive method and pattern recognition method does not lie in the main strategy (the ‘generate and test’ strategy), but on the methods realizing that strategy.

This interpretation conforms with the idea adopted in AI that a *task* can be realized by more than one method (see [Benjamins 93]). The most adequate method is selected on the basis of various factors such as the match between a reasoner’s experience in that domain and the knowledge required by the method. Consequently, although both hypothetico-deductive and pattern-recognition models include the same “task” of evoking hypotheses, they use different type of processes and different type of knowledge when doing that. Patel et al., being more concerned with showing the absence of hypothesis testing in expert reasoning, pays less attention to the fact that experts and novices also differ in hypothesis evoking strategies.

We are inclined to contend that the general process of diagnosis consists of hypothesis-generation and hypothesis-testing components. Hypothesis testing in the pattern-recognition model is embedded in the pattern recognition method which is applied exclusively by experts, as only experts own such patterns. As Elstein [95] recently maintains, experts’ hypothesis testing is usually “rapid, automatic, and often nonverbal”. In this model, hypothesis testing is not explicit. However, this may not always be so, and usually is not. The low level of expertise is not the only condition for the need to collect extensive data. Even the most outstanding experts may need to acquire more data when the data at hand is scarce and thus is not adequate for establishing a correct diagnosis. Patel et al. assume a sufficient degree of match when referring to pattern recognition. In general, experts use their past experiences, but nonetheless, because of a possible poor match, they may need explicit hypothesis testing by information gathering. In such cases, pattern recognition is followed by hypothesis testing similar to that in the hypothetico-deductive model. The match of patterns is not absolute. There may be various degrees of a match between two patterns. In the pattern recognition stage, the clinician “recognizes” whether she has sufficient knowledge and data or should gather more. It is her confidence in the hypotheses she has generated which determines what to do further.

Another important point is that the hypotheses should be evaluated regardless of what specific method is used for generating them. This is because hypothesis generation is an abductive process, and by nature generates fallible results. Irrespective of the method
used, the conclusions (i.e., hypotheses) must be evaluated; either by testing, or “pattern recognizing”. However there is an intuitive difference between these two kinds of evaluation, and we analyse this difference in the chapters where we elaborate abduction. We can briefly mention here that pattern recognition may involve the reasoner’s justification of her own reasoning. If she becomes able to perfectly justify her selection of the pattern from her memory and that this pattern matches sufficiently with the current case, then she may not see the reason for further testing her diagnostic hypothesis. However, if she is not confident of her hypotheses at the end of the pattern recognition step, she may try to verify the hypotheses by gathering further evidence. So, for experts, the pattern recognition process is decisive for determining whether testing a hypothesis in the same way as in hypothetico-deductive model is necessary or not.

The need for justification of one’s own reasoning behavior is, we believe, related to “metacognition”, an important factor which has not been given necessary prominence in these two models of clinical reasoning, but becomes a central factor in another model which we will soon present.

Theoretically, if after evoking a hypothesis it can be said that this is the correct diagnosis, then novices may also avoid the need for testing the hypotheses by gathering further data. However, this is often not the case.

It seems that a clear cut distinction between the hypothetico-deductive and the pattern-recognition models of medical reasoning is artificial as they are not necessarily mutually exclusive, and on the contrary, are usually practiced in combination. They can be considered rather as speciations or variations of the same process based on the generation and evaluation of hypotheses.

### 3.5 A model for integration of reasoning skills and knowledge

This is a model that integrates the content and the process, and may be considered as an alternative trend to the process-oriented models presented in sections 3.3 and 3.4.

This approach specially emphasizes the interrelationship between clinical skills and domain knowledge. The idea is that clinical reasoning skill can not be learned independently of relevant knowledge. For example, Schmidt et. al. concentrated on the domain specific knowledge and medical experts’ organisations of knowledge bases. It is, in fact the interaction between clinical skills and knowledge which underlies successful diagnostic problem solving [Barrows 91]. Schmidt et. al. investigated the model on developing expertise([Schmidt 90]; [Schmidt 93]; [Boshuizen 95]; [Custers 96]). They propose a three-stage model which emphasizes the simultaneous development of knowledge and skills.

#### 3.5.1 Three-stage model of developing expertise

Educational psychology is concerned with (a) arranging the curriculum in order for the students to quickly become experts in their field, and (b) enhancing performance. The medical field has been one of the faculties that most desperately seeks the answers to these questions.
The traditional learning/teaching method is based on a preclinical and a clinical period. The preclinical period is typically devoted to learning knowledge and acquisition of some skills, while the clinical period is for learning how to use those knowledge and skills. So, the acquisition of knowledge and its use are conceptualized as two distinct tasks.

Schmidt and his colleagues [Schmidt 90; 93] denied this view and proposed that development of expertise can not only be associated to acquiring more and more knowledge and skill, but that structuring knowledge is an essential part of improving expertise [Boshuizen 94]. This research group developed a “theory of expertise development in medicine” which describes expertise as

“...the progression through a series of consecutive phases, each of which is characterized by functionally different knowledge structures underlying performance. The first phase is characterized by accumulation of causal knowledge about disease and its consequences. Through experience with real cases, this knowledge transforms into narrative structures called illness scripts. The cognitive mechanism responsible for this transition are: Encapsulation of elaborated knowledge into high level but simplified causal models or even diagnostic categories and tuning through the inclusion of contextual information. The third phase is characterized by the use of episodic memories of actual patients in the diagnosis of new cases. It is assumed that knowledge acquired in different phases form layers in memory through a sedimentation process” [Schmidt 93].

So, according to this theory, knowledge is structured in the form of one of the following three types:

- principled causal knowledge (rather deep)
- illness scripts (less deep)
- cases (shallow, most specific)

The last two include a large amount of knowledge which is activated as a whole. We want to emphasize the role of context in the construction of such structures [Schmidt 90]. Context serves as a glue that connects clinical and biomedical knowledge so as to constitute a meaningful whole, either as an illness script or an episodic case.

The term “illness script” was first used by Feltovich and Barrows [Feltovich 84b]. In Schmidt and his colleague’s view, illness scripts describe features of prototypical patients. These structures include little deep knowledge related to pathological causes of manifestations, but rather clinically relevant information about diseases. An illness script is a cognitive structure consisting of three components and links together knowledge from these three groups of knowledge/information. These are:

1. enabling conditions which comprise the information about “circumstances in patients and their environment that may lead to illness” [Boshuizen 94, p 315]. This is the information describing the “context under which illness develops” [Schmidt 90, p 611]
2. the fault which is the “actual pathological process that is taking place” [Boshuizen 94], and
3. consequences, the signs and symptoms.
This research emphasizes the changes in the knowledge structure, contrary to approaches emphasizing the development of general problem solving and thinking skills. In this view, development of expertise in medicine is associated with a “transition from a network-type organisation to another type of structure”, the illness scripts. Thus, the approach implies that development of expertise can not be analysed independently from development of a particular type of memory, one consisting of what they call “encapsulated structures”. These structures “enable experts to grasp the structure of the problem and then proceed with solutions that bypass the novice’s lenghty search” [Glaser 90, p 33].

As to accessing knowledge in such a memory, “contrary to knowledge networks, illness scripts are activated as a whole” [Boshuizen 95] instead of as individual concepts. The expert’s hypothesis activation and testing is accounted as for by “epiphenomenon illness script activation and instantiation” [Boshuizen 95, p27]. In their account, episodic memory consists of instantiated scripts. And, these “instantiated scripts, in turn, do not become decontextualized after use, but remain available in memory as episodic traces of previously diagnosed patients, and will be used in the diagnosis of future similar problems” [Schmidt 93, p.208]. They emphasize essentially that all three types of knowledge (deep causal, illness scripts, and episodic cases) do not decay and do not become inaccesible. All are accessible at any time. However, the most specific and appropriate one is always preferred. What is most specific and appropriate depends on the problem at hand and the richness of the memory of the reasoner.

According to Schmidt and et. al. “problem solving in routine cases is a process of script search, script selection, and script verification” [Schmidt 90, p 615]. Cases are “instantiations” of illness scripts with concrete patient data and information. As experience increases, many such cases are accumulated. Notice that the word ‘script’ does not imply an emphasis on distinguishing between individual episodes and more general scripts. Hence, in our interpretation, this view suggests a coherence with the case-based reasoning paradigm.

So, in most familiar patient problems cases have been used, while in less typical problems, the illness scripts are utilized. As the degree of difficulty and atypicality increases, finding appropriate scripts or instances becomes difficult, and consequently more and more principled biomedical¹ knowledge gets utilized.

We would like to draw attention to the agreement between the ‘theory of developing expertise’ due to Schmidt et. al, and Patel and collegae’s association of expertise with application of a pattern recognition strategy. Criticizing the hypothetico-deductive account of the medical problem solving process, they also note that experts must have some patterns and match these with the new case rather than relying on principled knowledge.

Even though they call their theory “development of expertise in medicine”, as mentioned in [Schmidt 93], medicine is not a unique example of domains where problems are ill-defined; “Like medicine, many problems in the real world require some kind of diagnosis based on conceptual knowledge to characterize or understand a situation and act upon it in an appropriate way”.

1. The terms biomedical knowledge and core domain knowledge are used interchangeably throughout the thesis.
This memory theory can explain the findings of Elstein et. al. related to the superiority of outstanding experts in activating high quality of hypotheses, as we mentioned above. It has been shown that if the correct hypothesis is found in the hypothesis pool generated initially, experts recognize it as the ultimate solution. If it is not generated initially, on the other hand, it is not uncommon that it is not generated later either. Schmidt et. al. draw a connection between the ability of generating the correct hypothesis initially and the way diagnostic knowledge is organized. In particular, they explain generating the correct hypothesis early in the workup by the expert’s ability to activate appropriate illness scripts.

They relate this ability to experts utilizing enabling conditions much better than novices do. Especially when the data is scarce, the use of enabling conditions as additional information becomes significant with regard to performance. “Enabling conditions consist partly of nonmedical background knowledge.....patient contextual factors that influence the probability that someone has a specific disease (e.g., age, sex, previous medical history, current medication, occupation, hereditary and environmental influences, risk behavior)” ([Custers 96], p 385). So, experts are better able to utilize contextual and background information when generating hypotheses; a feature which makes them superior to novices.

An illness script represents a “whole” thing. It represents a contiguity, from start to end, similar to Schank’s scripts [Schank 77]. The relationship between the enabling conditions and the fault “is of a psychological and probabilistic, rather than of a medical or causal nature: For example, risky behavior (e.g., alcoholism) may in general increase the possibility that a particular disease (e.g., pancreatitis) is present, even though in a particular case, these events may be unrelated” [Custers 96, p385]. An important aspect with respect to enabling conditions is that they are usually available in an early stage of diagnosis.

### 3.6 The “holistic” model and metacognition

A more recent trend emphasizes the role of metacognition, which is ignored in other models, in addition to context use represented as a component of scripts and cases.

Chi recognizes three components of expertise as knowledge, cognition, and metacognition [Chi 85]. She argues that although knowledge, cognition and metacognition are all important in the development of expertise, none of them is sufficient for understanding expertise. She proposes that a holistic approach integrating domain specific knowledge, strategies and metacognition is necessary to account adequately for memory development. Considering any of these in isolation will not provide an understanding of expertise.

It has been suggested also that both medical reasoning and expertise can only be understood collectively in terms of knowledge, cognition and metacognition notions [Barrows 91]. Among these metacognition is probably the least investigated so far.

Higgs and Jones particularly emphasizes the prominence of metacognition in clinical reasoning. For them, “the ability to reason knowingly, and to justify articulately our decisions and interventions is essential for effective clinical practice and for the development of the knowledge bases of our professions” ([Higgs 95], p.3). They base their understanding of
clinical reasoning on the complex interactions of many factors. Many of these factors are encapsulated in the term “context”. They point out that clinical reasoning occurs in a specific clinical context. In their account, clinical reasoning occurs in several contexts:

“the immediate personal context of the individual patient/client, the unique multi-faceted context of the client’s clinical problem within the actual clinical setting in question, the personal and professional framework of the clinician, the broad context of health care delivery and the complex context of professional decision making. In order to understand and address the reasoning behind clinical decisions the various contextual factors that influence reasoning need to be appreciated ([Higgs 95], p 4).

Metacognition “refers to being aware of one’s own cognitive process and exerting control over these processes” ([Higgs 95b], p 141). Metacognitive skill is required in order to manage knowledge and other cognitive skills.

According to Biggs “High quality human performance inevitably requires metacognitive as well as cognitive components. To perform well, one needs to be aware not only of the knowledge and algorithms required for the task, but of one’s own motives and resources, the contextual constraints, and to plan strategically on that knowledge” ([Biggs 86], p 143, referred to in [Higgs 95b]).

Metacognition is a high level cognitive skill which is important for dealing with uncertainties, cognitive limitations, and ambiguities in clinical reasoning. It represents a self-monitoring ability of the clinician, which is needed to control and evaluate the knowledge and strategies (i.e., cognition) involved in clinical reasoning. It “provides an interface between general problem solving skills and domain specific knowledge” [Higgs 95b]. The following processes involved in metacognition are recognized: “realizing that important problem solving (task) information is missing or ambiguous, recognizing that the problem will be difficult..., being aware that reasoning errors have been committed, evaluating the effectiveness of reasoning strategies, modifying reasoning strategies and allocating cognitive resources” [Higgs 95b p 18].

In AI, the research community which concerns the reusability of elements of a system seems to deal with an equivalent of the notion metacognition. As we will see in details later, they attempt to explicitly represent all elements of reasoning at the knowledge level [Newell 82]. To mention briefly, the three “components of expertise”, according to [Steels 90] are domain, task, and method, which, in our interpretation, respectively correspond to knowledge, metacognition and cognition. Figure 3.1 shows this correspondence. Task knowledge links domain knowledge and cognitive methods to each other. It also mediates ‘what is my goal now?’, and ‘what should I do next?’ type of questions.
3.7 Learning of expertise

The issue of how medical problem solving ability can best be taught has recently gained much attention. So, medical research examined which method would most quickly and effectively educate student clinicians. Memory has been commonly accepted to have a determining role in developing expertise.

3.7.2 Principles of cognitive learning

The principles of learning are itemized by Schmidt as follows [Schmidt 93b]:

1. The prior knowledge people have regarding a subject is the most important determinant of the nature and amount of new information that can be processed.

2. The availability of relevant knowledge is a necessary, yet not sufficient, condition for understanding and remembering new information. Prior knowledge also needs to be activated by cues in the context of which the information is being studied.

3. Knowledge is structured. The way in which it is structured in memory makes it more or less acceptable for use.

4. Storing information into memory and retrieving it can be greatly improved when, during learning, elaboration of the material takes place.

5. The ability to activate knowledge in the long term memory and to make it available for use depends on contextual cues.

6. To be motivated to learn prolongs the amount of study time (or processing time, to put it in cognitive psychology terms), and, hence, improves achievement.

These principles imply that the learning context (e.g., classroom or clinic) influences the structuring of knowledge. Knowledge learned in the standard classroom context is
believed to be structured as a semantic network, while knowledge learned in the clinical setting is structured as packages in the form of scripts and cases.

The way to access and activate knowledge varies across different kinds of structures. The knowledge learned in one context can better be retrieved in the same context. For example, knowledge that can be easily retrieved in a clinical setting that which is previously learned in the same setting. We will see in a later chapter that this theory is true for almost all learning in all domains, and it is conveyed by ‘encoding specificity’ theory in cognitive psychology as well as shown by numerous experiments.

As we will see in this chapter, problem based learning has recently been proposed as an alternative to traditional teaching. It’s objective is teaching in a clinical setting context. The traditional curriculum, on the other hand teaches through books and lectures. Traditional curriculum has been criticized since students seem to be unable to use their textbook knowledge in the clinical setting because the kind of task needed in clinical settings require knowledge to be organised in another way such that access to it becomes possible.

3.7.3 Accessibility

Accessibility of knowledge is an important requirement. It is not enough that, as Chi notes, a person has knowledge. The knowledge must also be accessible in order to be used. Experts have this capability; although they have an extensive body of knowledge compared to novices, their knowledge is more accessible. “Whenever knowledge is relevant, experts appear to access it efficiently. The experts are therefore able to notice inconsistencies rapidly in favor of correct diagnosis” [Ericsson 91].

Particularly, knowledge structured in forms of scripts and cases must be stored in a way that makes it possible to recognize the similarity with a new patient case and fetch the memory chunk as a whole, including the visually similar parts as well as the potentially similar or potentially dissimilar ones. This becomes possible, according to Schmidt et. al.’s theory, since the interrelated parts of knowledge are encapsulated in scripts and instances. In these ‘packages’ lower-level concepts such as symptoms and patient’s personal information (i.e., context) are more often referred to in favor of causal, underlying, biomedical principles [Schmidt 93]. This makes it easy to access by using information at hand, which also is usually in terms of lower-level concepts.

3.7.4 Learning as developing memory

As the process oriented approach to understanding medical reasoning attempted to explain development of expertise in terms of procedures and skills, a similar mentality attributed the deficiency in young children’s performance to the absence of mature strategies. That is, children’s inability to solve a problem is attributed to their lack of reasoning skills. However, Chi [Chi 88] provided evidence on that the lack of knowledge or inability to access the available knowledge could also be responsible for such deficiencies. Even though the young children have acquired mature strategies, they may be unable to solve the given problem because of either lack of knowledge or inadequate representation of knowledge leading to difficulties in accessing it [Chi 87].
Chi analyzes and examines how the knowledge structure in children changes with age. She defines memory development as the change in performance with age, in all kinds of memory tasks, such as recalling a sequence of digits, reconstructing experienced events, etc. Chi argues that in order to be able to use a given strategy, the young children have been observed to rely on the knowledge in their semantic memory. That is, even if the cognitive strategy necessary for solving a problem is available in the child’s stage of maturation, the child may be unable to use it. This happens if the amount and structure of content knowledge required by the strategy is not already acquired.

Chi’s argument agrees with Schmidt and colleague’s which may be considered to take this idea a big step further towards a theory of developing the expert’s memory. There is a parallel between Chi’s examining age-related differences in memory and Schmidt and colleague’s (in Limburg) analysing the development of clinicians’ memory by experience. The Limburg group argues, similar to Chi, that in order for a clinician to make a fast and efficient hypothesis activation, she must already have acquired the required knowledge structured as illness scripts and patient cases.

It has been hypothesized that development of expertise in the medical domain leads to structural changes in a physician’s domain knowledge. Schmidt’s team examined the changes in the knowledge structure reflecting change in the level of medical expertise. Based on the findings from their experiments Schmidt and Boshuizen provide a theory of memory development of experts, as we have seen in the preceding section.

The three-staged memory development theory can be considered, at the same time, a learning model. According to this model, learning happens through transformation from one structure to others, starting from network-like structure and ending with illness-scripts and patient instances. This is a continuous, life-long process. We agree with Higgs Jones who “regards knowledge as a construction of the human mind seeking to make sense of the world, rather than something that is discovered” [Higgs 95, p 10]. This approach is also reflected in AI, by the case-based reasoning paradigm ([Kolodner 93]; [Aamodt 94b]). Aamodt [Aamodt 91] calls this as “sustained learning” which implies the continuity of constructing new memories. This will constitute an important foundation for our study of context knowledge and our managing of context knowledge in an AI perspective.

3.7.5 Teaching clinical reasoning

“The objective of medical schools is to turn relative novices into knowledgeable and skilled professionels” [Boshuizen 95, p24]. The question is how to do this. Educational psychology investigates this subject. Two dimensions of a curriculum is what to teach and how to teach.

The first step is to analyse the type of knowledge necessary to learn for developing expertise. Knowledge to be taught has been classified in two main groups: basic science or biomedical knowledge, also called textbook knowledge, and clinical or heuristic knowledge. Basic science knowledge\(^1\) in medicine includes anatomy, biochemistry, physiology, microbiology, histology and pathology. Heated discussions are centered around questions

\(^1\) We call ‘basic science knowledge’ as ‘core domain knowledge’ in later chapters.
of which type is more important for problem solving performance, and which sequence these should be taught, or should they be taught simultaneously. The answers to these questions would also shed light on the question of how the memory of experts is organized and structured, what type of knowledge they do own, and the depth and breadth of that knowledge.

3.7.5.1 Distinction between “textbook” knowledge and “heuristic” knowledge

Research in medical education states that in training of medical students the primary emphasis has been on complaint exploration and physical examination [Hobus 87]. Consequently, the anatomical and pathological type of knowledge has been given the most importance, since this sort of knowledge is used for understanding the relations between the symptoms and signs, and diseases. An example of a typical textbook subject is “Myocardial ischemia means reduced blood supply to myocardium which in turn reduces myocardial compliance. This implies diastolic dysfunction (decreased ability to expand) which causes the ventricular diastolic pressure to rise, which leads to abnormal S-T segment changes. The patient may experience angina pectoris. The rise in the diastolic filling pressure may cause some patient’s experiencing acute dyspnea. The reduction in the ability of left ventricle to contract causes reduced cardiac output which cause some patients to feel fatigue...”. This example is on the pathophysiology of myocardial ischemia.

It has also been stated, however, that other source of knowledge are needed in critical points of a diagnostic process. An example is how a patient’s age, sex and race may favor certain disease. When the muscular system is regarded, juvenile rheumatoid arthritis or rheumatic fever are more common in children, while reiter’s syndrome or systemic lupus in young-adults, fibrosis in middle age, and osteoarthritis in old age. Regarding race, SLE and sarcoidosis are more usual for negroes while polymyalgia rheumatica is more often observed in caucasians [Greenberger 93; Wright 79].

In one meeting, our medical expert was interpreting the signs and symptoms of a patient with cardiological problems. The patient was a black male. The doctor was suspecting an infectious disease. At one point he said “... he is black... he may have tuberculosis...”. When we asked him later why he associated the patient’s being black and the possibility that he had tuberculosis, he looked at us for some time, because he did not remember having said that. Then he remembered, but needed some time in order to find out how he may have thought. He said “black people usually have lower economical... and therefore malnutrition...tuberculosis...”.

Another example of the type of knowledge that usually does not exist in medical text books (from [Wright 79], p124): Sarah aged 3, the first child of professional parents (the mother was a practicing doctor, and the father a consultant engineer) brought to the doctor with severe limp following a fall downstairs. Examination showed no bruising, while X-rays showed a transverse fracture. Further conversation revealed major marital conflicts, centered around the competing career claims of her father and mother, and vented on the child who had been impatiently pushed down the uncarpeted stairs of the newly-occupied house. There are several points to notice here. The doctor had been told that the child had

---

1. Md Ole Rosvol, cardiology, RIT, Trondheim
fallen, and he found a transverse fracture. So, the cause of the fracture was the falling. Establishing the cause of a symptom is at the heart of diagnosis. The concept of ‘cause’ may be rendered to be more complex when it is elaborated. As in the Sarah example, the cause of her sign (fracture) has another cause, that is the family problem. In fact, for every cause there exists, in turn, another cause. “Family problems” is neither an anatomical nor a pathological type of knowledge; it is not of the biomedical type. It is of “another” type.

A doctor, after having experienced such a case, will probably remember in the future that people with psychological stress and problems may be careless and this may lead to similar unpleasant consequences. A doctor may, in some cases, infer from the patient’s appearance whether she is under stress - sometimes from her hair style and care, dress, finger nails and cleanliness, or from her attitudes.

3.7.5.2 Problem-based vs traditional curricula

An important question (much discussed in the educational psychology community) is which teaching - or learning- paradigm offers the best method for developing medical problem solving capability. This discussion further opens another discussion, on the roles of biomedical and clinical knowledge in clinical reasoning. In fact, the role of biomedical knowledge has been revealed to be an important characteristic in order for understanding the differences between experts and novices.

In the traditional curriculum “students gather in classes to acquire knowledge, have practicals for demonstration purposes, follow skills training programs and have their clerkships” [Boshuizen 95, p24].

The problem based learning paradigm is a result of the search for a new curriculum. This search may be seen as a search for a new learning context which may be closer to the context of using the learned knowledge. Thus, the aim of changing the learning context was to reorganize the structure of the knowledge [Neame 84].

In a problem based curriculum, the students are given a clinical problem to solve either in a simulated or a real situation. Learning happens around the problem, and thus is problem-oriented.

Both the type and structure of the knowledge learned by these two curriculum is different. Traditional curriculum emphasizes teaching biomedical knowledge while problem based learning emphasizes low-level concepts such as symptoms and patient’s occupation, age, etc.

It is proposed that problem based learning can be characterized by the following aspects [Schmidt 93b]:

1. Activation of prior knowledge- the initial analysis of a problem stimulates the retrieval of knowledge acquired earlier.
2. Elaboration of prior knowledge through small-group discussion, both before or after new knowledge has been acquired; active processing of new information.
3. Restructuring of knowledge in order to fit the problem presented. Construction of an appropriate semantic network.
Learning in context. The problem serves as a scaffold for storing cues that may support retrieval of relevant knowledge when needed for similar problems.

Adoption of a problem based approach to learning seems to be a “contextual reform of medical education. Context is used to describe the style of the teaching, the structure of materials and the framework within which the content is presented” [Neame 84]. This approach is based on the idea that the context in which the material is learned influences the development of knowledge and understanding, and subsequently the way in which the learner can use this knowledge. Barrows states that problem based learning is adequate for acquiring retrievable and reusable knowledge. “Retrieval and use of information in the task context, in medicine the clinical context, requires that the information be learned in clinical context, so that cues that appear while working in the task situation will stimulate retrieval of the appropriate information by memory association” [Barrows 84, p19].

It has since long been recognized in cognitive psychology that successful retrieval happens when the cues relevant to its retrieval are encoded with the information to be stored [Tulving 73].

Barrows criticized traditional curricula as not providing cues that would facilitate the medical students’ remembering their knowledge in clinical practice. “In the traditional medical school course students will organize knowledge around definitions, lists, models of interrelations, and by taxonomies relevant to the subject matter. The teacher’s test will provide cues relevant to this organisation of information to stimulate the recognition or recall of the knowledge acquired by the students. For example, memorizing the twelve cranial nerves and their pathways and subsequently describing the sixth nerve on a written test does not organize information in a manner particularly useful for understanding patients with brain stem lesions that will be encountered later” [Barrows 84, p19].

Cognitive psychology has also found the “depth of processing” information prominent for learning and subsequently remembering a phenomenon [Craik 72; Craik 75]. In the medical domain, Neame emphasized that elaboration in learning time explicates which information can be a useful cue for future retrieval of an experienced patient situation.

In order to promote understanding, it is necessary for the learning to ‘elaborate’ on the knowledge, to turn it over in his head and establish its relationship to other information both newly acquired and already existing in his memory. Thus the inference appropriate to medical education seems to be that learning should be clinically oriented, preferably based on patients. It is also important that the information to be learned is structured ((when))).

According to Barrows and Tamblyn [Barrows 80], the role of groups discussions is that the students explicates which information is relevant or important and in which way. This leads to encoding such information as retrieval cues for future use. The underlying reason is that through discussions, students explain which cues and why they are important, by linking them to other meaningful concepts. A support to this hypothesis is due to Chi [Chi 89], who investigated the role of self-generated explanations that the students generate while studying worked-out examples of mechanics problems. She suggest that the “good learners” are the ones who generate thorough self-explanation of the to-be-learned sub-
jects while “poor learners” generate insufficient explanations. The role of explanations has been emphasized also in AI. In chapter 11 we will elaborate how the role of explanations are emphasized in the framework of the Creek system [Aamodt 94].

Critiques of problem based learning and its application to medical education are also based on a context notion as its proponents do. Patel et. al. compared performance of students from traditional and problem-based schools. They maintain that students from PBL school are not able to “decontextualize” the problem, that is they can not remove basic science knowledge even when the clinical situations requires that. This initialized the investigations and discussions of the role of biomedical knowledge.

**The role of biomedical knowledge.** We can briefly present the question as such: whether the roles of biomedical and clinical knowledge are rather distinct and these can be considered as two different worlds [Patel 91], or whether biomedical knowledge is fully integrated in clinical knowledge. Patel et. al. advocates the first alternative suggesting that basic science plays its role when generating a coherent explanation of the patient problem connecting various components of the clinical problem. Its role is not facilitating clinical reasoning itself. The “explanation” mentioned here must be the explanation offered by the physician to third parts (the experimenters, for example, investigating the role of biomedical knowledge), after establishing the diagnosis. The proponents of the second account, Boshuizen and Schmidt and Talmon, argues that both biomedical and clinical knowledge play a role in clinical reasoning itself. However, their roles are different and occur in different phases of clinical reasoning. Biomedical knowledge “plays its role in a tacit way, leaving no trace in the think-aloud protocols” [Boshuizen 91]. In their account, the expert resorts to biomedical knowledge, in atypical cases, and when the illness script partially fits the current case. “Biomedical knowledge was supposed to be used to explain why atypicalities occur in a specific case” [Boshuizen 91]. According to this account, clinical knowledge is used to interpret and order/structure available information, while “biomedical knowledge seemed to be applied for a justification or explanation after the interpretation had been made” [Boshuizen 91]. So, the information is first interpreted, and then the interpretation is justified. This is a rather important proposition for us, as the “justification” here corresponds to what we call “justification of one’s reasoning” in connection to abductive reasoning. This is a natural process, especially when encountering a problem where information and data at hand is not sufficient for reasoning with certainty.

So, in the “Limburg account”, clinical knowledge is used for generating useful hypotheses while biomedical information is used to elaborate on the information that does not seem to agree with these hypotheses. This account recognizes the need for links between clinical and relevant parts of biomedical knowledge.

Findings from experiments conducted by both approaches show that

1) Experts use less basic science knowledge than novices or interns.
2) Atypical cases require more basic science knowledge than typical ones.

The reason why interns or novices use more basic science knowledge is that problems are more difficult or atypical for them [Barrow 91; Boshuizen 91].
3.8 Conclusion

This section presents a brief interpretative summary of this chapter, which addresses various aspects of medical problem solving. The points that are important for our work can be summarized as follows:

- The problems where the reasoner is compelled to work with uncertainty occur when the available information is not sufficient to solve the problem, but collecting more data and information is necessary, a generic strategy of hypothetico-deductive process is employed. This is the case in diagnostic problems as well as in scientific inquiry [Barrows 94].

- There are usually differences between experts and novices regarding both hypothesis generation and verification.

- Experts and novices may differ in both depth and breadth of “general domain knowledge”. Experts may be capable of using far more kinds of knowledge. That is, experts are superior regarding the quantity and variety of knowledge at their disposal.

- When solving difficult, atypical cases, the reasoner resorts to basic science knowledge. Basic science knowledge that justifies one’s own reasoning by explanation. For example, the physician needs to explain how the hypotheses fit with the available data in order to increase her confidence in the generated hypotheses.

- Both experts and novices use basic science knowledge, but novices use it more often than experts. This is because far more cases will be routine and familiar to experts than to novices. Familiar cases are also referred to as “well-structured” possibly because the expert can impose a structure on them by using experience. The difficult cases are considered to be “ill-structured” or ill-described.

- Patient cases that become “typical” for a clinician (due to repeated occurrences), lead to transformations of related knowledge into structured knowledge packages in the form of “illness scripts” and “patient cases”. An increase in the number of such packages does not mean a decrease in biomedical knowledge, which may also increase in time, and can be resorted to when needed.

- Automatic reasoning implies finding such packages in order to generate hypotheses. If the retrieved package does not perfectly fit the information and data at hand, there will be varying degrees of uncertainty, depending upon the quality of the match. An elaboration on general domain knowledge\(^1\) may result in sufficient certainty in a hypothesis. In this case, further testing by collecting data may not be necessary.

- Experts reason flexibly, since they have and are able to make use of knowledge from various disciplines on the periphery of medicine. This is called as “context knowledge”, which augments the knowledge base of the physician both in “network-like” and in “package” type knowledge. Devine and Kozlowsy [Devine 95] found that experts acquired considerably more contextual information than novices across all conditions, regardless of whether the case was well- or ill-structured.

\(^1\) This includes both biomedical knowledge and common sense knowledge.
• High level experts are believed to be superior in structuring on ill-structured problems. As Devine suggests, adding structure to a problem requires information. Context is such an information source and is used especially by experts. In fact, researchers explain the incremental accuracy of experts in comparison with novices in medical domain by the experts’ use of contextual knowledge [Hobus 87].

• Biomedical and clinical knowledge¹ are linked. The knowledge structures such as prototypical illness scripts and cases are hooked to biomedical knowledge. This contention is reflected in AI, where explanation-based and case-based reasoning are integrated [Aamodt 94].

• Hypothesis generation is an abductive process which may be performed in different ways depending on the level of expertise and experience. All hypothetico-deductive processes apply abduction as the first step, and abduction may possibly be reused later during work-up, since hypothetico-deduction does not impose a linear process [Barrows 94]. Psychology investigates abduction as the first step of discovering (i.e., generation) new ideas. The focus was not on how this process may vary across various levels of experience. However, it has been intuitively recognized that hypothesis generation is a “guess” that becomes an “educated guess”, in proportion to increasing experience. In this connection, the role of “familiarity” has also been referred to [Peirce 58]. We study the use and role of different kinds of knowledge in generation of disease hypotheses via studying abductive inference, in chapters 4, 5, and 6.

¹ Medical researchers use clinical knowledge in order to refer to what we call ‘peripheral domain knowledge’, that is contextual knowledge.