Chapter 2

Medical problem solving

2.1 Introduction

Our aim in this chapter is to identify the principal components of medical problem solving on the basis of 1) what the medical experts think these components are 2) how research in educational psychology characterizes expertise.

The first part of the chapter (sections 2.2-2.4) can be seen as a survey of medical reasoning research literature. Our goal, in fact, is to be able to transfer these components from the human expertise plane to a computational expertise plane. That is, we use what we filter from medical experts’ introspection related to how they solve medical problems. At the most abstract level, medical professionals mention three elements as covering the abilities of a medical expert. These are reasoning skills, physical skills, and knowledge. We aim at a model that captures reasoning skills, physical skills and the memory of the medical professional, in terms of task, method and domain knowledge. In this part, we take a look at the human model of expertise as reported by medical diagnosticians themselves.

The second part of the chapter (starting from section 2.5) discusses various accounts of expertise and its development. A particular emphasis is put on the impact of the structure and content of knowledge on the reasoning performance. The conclusion we draw in this part highlights the importance of the illness scripts/cases and the contextual knowledge.

2.2 Main considerations of a clinician

Time pressure is a characteristic of medical problem solving. The physicians are responsible for quickly deciding whether the case is urgent, whether they should initiate some treatment, or they have time to make a correct diagnosis before they start a therapy. For example, in the case of traumas and sometimes in cases of infectious diseases, the doctors may not have enough time to find out exactly what has happened, but they nevertheless need to initiate some form of treatment in order to avoid an unrecoverable development of the illness.

From the view of the patient, the clinician listens to the complaints, asks questions, examines the patients, orders laboratory tests, and writes a recipe or proposes a clinical intervention such as surgery. This is a mental picture of the clinician’s problem solving in the patient’s head. For our purpose, what is more important is the mental picture in the clinician’s head. Such a picture (see figure 2.2) can help us to identify the types of knowledge/information that assist the clinician in various stages of the process, as well as to identify these processes themselves. We will first identify the reasoning skills, domain knowledge and the physical skills that an expert possess. This is the static aspect of our modelling problem. A more dynamic aspect is related to linking these three components, that is
explicating which reasoning skill needs which type of domain knowledge and which type of physical skill has relation with which type of information, etc. We start with determining, from the medical experts statements in the literature, and our talks with medical experts, the static elements of the expertise. We will then recognize the links between these three static elements which will guide us towards a holistic picture of medical expert’s problem solving that can be used for the purpose of modelling a computational expert.

Wright and Macadam [Wright 79] summarizes a clinician’s overall concerns under four questions:

What is wrong?,
Why has it happened?,
What is going to happen?, and
What should be done?

The attempts to collectively answer these questions are embedded in the diagnosis and treatment process. The first question is related to the features of the case which have been rendered abnormal. That is, the expert notices the abnormal findings, in addition to what the patient complains about. The words used for conveying these features are important for our purpose, because we should include these in our domain model. The second question seeks an answer to ‘what disease has caused these abnormal features’. The diseases are also important entities in the domain model. The third question asks what more can be expected to be observed of a patient over time. These “to be expected’s” are also findings (or manifestations) and will be included in our domain model. The last question concerns also which action to take in order to establish a diagnose. For example what questions to ask to the patient (referred to as history taking or interviewing), what laboratory tests to order(referred to as laboratory investigations), what physical examination to perform, etc. Further, after establishing a diagnosis, a proper treatment needs to be suggested. For our purpose this means that we should include in our domain model the physical actions that support diagnostic explorations or therapy.

2.3 Overview of Clinical practice

Problem solving in a medical setting may be likened to solving other problems in the real world. For example, the reasoning of a detective solving a criminal case, or the method used by scientists conducting empirical research.

All are ill-structured problems. The main characteristics of ill-structured problems are their having inadequate information at the outset, and the lack of definite guidelines for solving the problem. In both domains the information is insufficient at the outset in order to jump to the result directly.

Instead, the problem solver generates a set of possible, tentative hypotheses suggested by the available information. These hypotheses then guide further exploration of the patient’s problem. So, selection of the strategy for gathering information is guided by these hypotheses.
Needed information can be gathered in clinical problem solving via various invasive and non-invasive methods such as interview, examination, X-ray, etc. The possible questions that a doctor can ask to the patient, or possible examinations she can perform are infinite. The process of information gathering is guided by the disease hypotheses that are tentatively generated early in the patient encounter. The process of hypothesis generation will be referred to as *abduction* in later chapters. The hypotheses indicate the manifestations that can be expected to be observed if the hypotheses are correct. The process where hypotheses guides the expectations as to what will be observed is referred to as *prediction* in later chapters.

The gathered information is analyzed to judge whether it leads to re-definition of the problem- this process is referred to as *induction* in later chapters. The collection of information that becomes available as time goes by may change the clinician’s understanding of the patient’s problem. This procedure may entail that none of the hypotheses can adequately explain the symptoms and signs observed so far. Then, new hypotheses are generated which guide further clinical investigation until either they are shown to be inadequate, or one of them is judged to be the true cause of the patient’s problem.

Identifying the following stages of the overall process can help to conceptualize the cognitive behavior of the professionals when handling patient problems, as adopted from [Barrows 91]:

1. Perception of the initial cues - forming initial concept
2. Rapid generation of hypotheses
3. Formulating an inquiry strategy
4. Applying appropriate clinical skills in order to apply this strategy
5. Interpretation of the new data and reformulation of problem if necessary
6. Diagnostic and therapeutic decision making.

The literature indicates that medical problem solving does not, in fact, constitute a sequential processing involving these aspects. For example, the doctor perceives the initial cues that she assesses to be important at any point in time. She may, as the process proceeds, realize that the cues she was not aware of earlier, turn out to be rather important. On the other hand, the interpretation of new data may reveal that the initial hypotheses are not adequate, and she may need to generate new ones. That is, from stage 5, she turns back to stage 2. Our computational model of diagnostic process reflecting this cyclic process is presented in chapter 9.

These are the main tasks of a medical professional. However, different professionals may accomplish these tasks by using different reasoning skills and physical skills. These skills are captured in our model as “methods”. In the following sections we go through these six stages and try to look into the characteristics of each stage (e. g., what kind of input is needed to accomplish each stage, what is the output of each stage). This will guide us in determining what needs be modelled in order to capture the medical expertise. It is, at the same time easier to analyse the knowledge involved in medical problem solving when the whole process is partitioned into smaller subprocesses. Another advantage of partitioning
the whole process is that we can readily relate the particular type of knowledge to the sub-processes where it is used. This simplifies the dynamic portion of our modelling job.

The strategy of decomposing a process into its subprocesses (i.e., reasoning tasks and physical tasks accomplished by the medical expert), has been of vital importance for our aim to study the notion of context in a diagnostic framework. By partitioning the diagnostic process, we were able to identify the various types of contextual elements, as well as the points where they are used (see section 6.4).

In the rest of the chapter we follow Barrow’s six steps. However, the content of each subsection is not necessarily due only to him, but has been gleaned from the medical research literature ([Wright 79], [Elstein 78]). For the purpose of our research, the most important steps are the first three. Therefore they have been focused on in more detail than the last three.

**Initial Conception; Perception of initial cues**. At any time there is usually more available information than what a medical expert can handle. The initial conception is shaped by what the physician perceives, and reflects her synthesis of what she perceives. Thus, the initial conception is a transformation of the real world situation into a mental image in the physician’s head. It is this conception that further guides the diagnostic process. This conception may change as new information becomes available. It is important at this stage that the physician includes as many relevant cues as possible and excludes irrelevant ones. The ability of doing so is dependent on the experience of the expert. Experienced physicians gather far more relevant cues than what the patients volunteer ([Barrows 91], [Harvey 79], [Taylor 88]).

Since the interview with the patient is of crucial importance, it would be fair to examine the possible obstructions that may impact the communication. Some of these are related to the patient and may be a result of emotion, anxiety, fatigue, drugs, or depression. Others are related to the expert, which again includes emotions, impatience (e.g., time pressure) and preoccupation (e.g., recent quarrel in the family) [Wright 79].

The environmental conditions may also hinder a pleasant communication. For example, the room may be too warm or smell bad, or the light may be inappropriate. An extreme example will be a patient-doctor encounter occurring in a war zone.

We consider these obstructions as portions of contextual aspects of an interview. In fact, we have found a significant correspondence between the results from empirical studies in cognitive psychology and the medical experts’ statements on the three types of obstructions that may arise in an interview session. As a result, we highlighted three dimensions of context; the problem solver (the medical doctor) related one, the target-related (the patient) ones, and the environment-related ones. These correspond to the grouping which the medical experts does when explaining possible obstructions that may arise in interview.

The cues important to one clinician may be unimportant to another one. So, the value of a particular fact may be subjective. This is stated to largely depend on the clinician’s past experiences and on the objectives determined by the health-care setting, in which the interview takes place, for example hospital ward, ambulance or war-zone [Barrows 80].
The components of a medical interview have been divided into six groups [Greenberger 93]: chief complaints, history of present illness, past medical history, family history, social history, review of systems.

Included in a past medical history are all the past events of type pediatric, medical, surgical, psychiatric and obstetric. In a family history, the causes of death, age of death, living environments, and family disorders are included. Social history includes work conditions, stressful situations, home life, etc.

We distinguish between these various type of information gathered in interviews some are included in our core-domain entities while others in contextual domain entities, as will be seen in section 8.3. The following example is presented in order to illustrate how important a role the medical expert’s knowledge can play in peripheral domains when solving a patient problem (see figure 2.1). The following example illustrates the importance of knowledge from peripheral domains for a faster and more accurate interpretation of the patient’ problem (from [Barrows 91]):

A 54-year old Saudi Arabian Bedouin immigrant in USA complains of bilateral ankle pain associated with activity. The patient does not speak English. The physician is American. The patient’s wife translates. The wife is in traditional clothes. The patient himself is quite shy and walks clumsily. He works in a lumber warehouse. In the examination the physician notes that the patient has lax ankle joints. There is no sign of inflammation or deformity. He has significant loss of light-touch, pin-prick and vibration sense throughout his feet. The muscles of his feet and legs are normal. The physician suspects a peripheral neuropathy. She based this hypothesis on the following possibilities emerging from the background of the patient:

- infectious diseases of the middle east such as bejel or leprosy.
- exposure to toxin, which may be caused by chemicals used in the lumber industry.
- a deficiency in nutrients such as B12, which may be due to change in food culture.
- side effects of traditional home-made herbal remedies.

![FIGURE 2.1 Medical reasoning relies on knowledge from peripheral domains in addition to medical domain knowledge. Medical experts use a diversity of other (contextual) cues in addition to pure medical cues.](image-url)
If the patient is not an Arab, the physician would tend to ask his alcoholic habits, but as muslims do not drink and he seems rather traditional the physician takes it as given that he does not drink. This reasoning failed, since he was a Bedouin, Christian, and, in fact an alcoholic. Her ignorance in other disciplines than basic medical science played a detrimental role in her diagnostic performance. Figure 2.1 suggests that the common sense knowledge of a medical expert may interact with medical problem solving. The case of the 54-year old Saudi Arabian Bedouin is an example of how medical experts use their knowledge from a number of domains on the periphery of medicine, which is of type common sense knowledge.

The cues picked out in an interview are interpreted so as to synthesize, possibly tentatively, an ‘initial conception’. This interpretation to an initial conception is based on the past experience and beliefs of the physician. Hence, past experiences, determine both what cues to pick out and how to interpret these cues. As will be seen in the next chapter, possession of experience and its use has been associated with the degree of expertise.

**Hypotheses generation.** A hypothesis, according to Webster’s dictionary (Random House, 1989), is “a proposition, or set of propositions, set forth as an explanation for the occurrence of some specified group of phenomena, either asserted merely as a provisional conjecture to guide investigations (working hypothesis) or accepted as highly probable in the light of established facts”.

It has been observed that experts are able to generate one or more working hypotheses rather early in the first encounter with the patient. Even from only knowledge of age, sex and the main complaints of the patient experienced physicians can make a ‘guess’ related to the cause of the complaints. What activates these hypothesis in the mind of the clinician? Is this an art? Peirce who studied the role of abductive inference in scientific inquiry method states that hypothesis generation is a guess, but a ‘skilled guess’. The term ‘skill’ as he uses is closely related to the experiences and beliefs of the reasoner. According to [Barrow 80, p. 23] who studies the learning of medical problem solving, the hypotheses are “usually a product of the clinician’s past experiences with patient problems. Their retrieval from the physician’s memory bank is largely an unconscious act of memory association”. Patel and Groen [Patel 91] also emphasize the phenomena of ‘enhanced recall’ in connection with the expert-novice comparison in the medical domain. Enhanced recall refers to the fact that “experts have superior memory skills in recognizing patterns in their domains of expertise”.

A new hypothesis is activated, according to Kassirer and et al.[Kassirer 85] whenever:

- there are some manifestations to be explained. A cluster of these manifestations may activate a hypothesis

- the new information contradicts an already existing hypothesis which has been considered.

Generation of hypotheses is of crucial importance as they guide the gathering of further information to help decide which of the hypotheses in the pool is the correct diagnosis.

Hypotheses may be of diverse sorts, depending on the goal of the medical expert. In a hospital-ward, the goal is to generate an explanation of patient complaints. Then the hypothesis may be etiological. However, if the encounter with patient occurs in ambulance,
diagnosing will hardly be the goal. A typical goal would be managing the bleeding. Accordingly, a hypothesis can be an adequate method of managing bleeding.

The information collected during an interview contributes to hypothesis generation. How this exactly happens is still a research subject. One important point that has commonly been emphasized in the literature is that past experiences play a crucial role in hypothesis generation. So, hypothesis generation is possibly a product of a process linking the cues available in interview, past experiences, and the expert’s professional knowledge. What the term “professional knowledge” includes is also a relevant question here. For example, the knowledge that ‘psychological stress may cause people to act carelessly’ is included in the physician’s “professional knowledge”.

Hypothesis generation is the process from concrete and specific information to more abstract knowledge that explains this information. The initial conception may be a step toward linking those most specifics to most abstracts. Computational approaches to diagnosis have utilized the concept of abstraction. Clancey’s heuristic classification is an example based on abstraction from data. In this approach, a move from data to a ‘data abstraction’ allows the reasoner to make heuristic matches between the data abstractions and patterns of problem solutions [Clancey 85].

A physician may generate a hypothesis either directly from cues, or more usually first proceeding in steps upward to initial conceptions and then to hypotheses. It depends on the existing connections between concepts in the memory of the physician. The cues which are the observables are available earliest in the patient encounter. Initial conceptions are rapidly constructed by combining various subsets of cues. The combination of initial conceptions enables the physician to reach a diagnostic hypothesis. However, sometimes, “the clinician recognizes - identifies - a patient’s illness as a case of a disease because the physician has memorized the elements that make up that pattern when elements of the right kind are present in combination”[Albert 88, p 179]. In this way the physician may reach the most abstract level (i.e., hypothesis) without consciously moving through the whole chain connecting cues to hypotheses.

The endeavors of both initial conception and hypothesis generation can be considered as attempts to transform an open-ended problem to a more closed, that is, to a framed one [Barrows 84].

A clinician can not generate hypotheses until she starts to understand the patient’s situation. If the clinical findings are scarce and of a general type that can be associated to very many hypotheses, the clinician would not be able to generate adequate hypotheses. The expertise reveals itself in the ability to quickly find additional cues that contribute to making a meaningful cluster of manifestations. An example of using such an additional clue is inferring from the perceptible deformities in the patient’s physiology that the patient is abusing alcohol.

Once a set of hypotheses form in the mind of the physician, she needs to acquire more information to shape or refine her temporary hypotheses. The medical experts use a variety of information gathering techniques such as interview, physical examination, and laboratory tests. This process, again according to Barrows, involves a “deductive, problem-oriented” reasoning.
Formulation of inquiry strategies. The generated hypotheses guide the physician’s inquiry in pursuit of gathering more information and data from the patient. More information is needed so as to support or weaken the hypotheses temporarily generated. By Barrows statements the hypotheses guides the physician in selecting “a strategical sequence of inquiries designed to ferret out data that will deduce, verify, deny, focus, or rank the hypotheses in his head in the most efficient and effective manner possible” [Barrows 80, p 27]. That is, further inquiry following hypotheses generation is necessary for evaluating the generated hypotheses, and recognizing the most probable one.

Nevertheless, there is no straightforward way of acquiring new information. The generated hypotheses plays a particular role in bringing a structure to information gathering. Barrows [Barrows 80] characterizes the physician’s inquiry as a combination of “search and scan” processes. The physician performs a ‘search’ when she knows what she is going to look for. She has some expectations and checks whether these are true. The expectations are imposed by hypotheses. Quite often she attempts to confirm or rule out a hypothesis. However, when she does not know what to do to differentiate between hypotheses, she may use ‘scan’ type of questions.

So, hypotheses are used to generate expectations related to what would be true (i.e., which manifestations) if the hypotheses were correct. The expert predicts the manifestations. The manifestation that are not yet known should be gathered.

Applying appropriate clinical skills. The physician, after deciding which further information she needs, makes a plan for acquiring that information. Then she starts to apply the plan which involves taking some actions. This is where the physical skills may be needed. The choice of the way to acquire a needed piece of information depends also the setting (i.e., location), since different settings provide different opportunities. For example in a war zone, physicians have restricted resources. We include the physical actions that an expert takes in our core domain model, while the factors such as availability of X-ray machine is included in contextual factors.

Interpretation of new data and reformulation of the problem. The physician reviews her understanding of the patient as new information or data becomes available. This may entail changing her hypotheses if the expectations and observations are contradictory. Not all such data triggers the generation of new hypotheses. For example, a new fact which is rather general, such as fever, would not lead to activation of new hypotheses. More specific data may be of significant value, while fever is of low value.

Diagnostic and therapeutic decision making. On the basis of the degree that the manifestations and the hypotheses fit together, the expert decides upon the ultimate diagnosis. This process may vary from expert to expert. Some may make final diagnoses earlier than other and by using less information.

For each diagnosis, there may be a number of therapeutic alternatives. The choice among this set depends on various factors, many being contextual ones. For example, the age of the patient or the allergies, as well as the environmental factors such as availability of required instruments for the selected therapeutic method are important for making this decision.
2.4 The correspondence between cognitive and physical activities

In the preceding section of this chapter we tried to allow the reader to see our perspective, needs and interpretations with respect to the clinical problem solving. Based on various approaches in the literature that attempt to explain the clinician’s problem solving, we configured figure 2.2 showing our understanding of how a medical expert does her task. We did this without explicitly stating what the mentioned perspective, needs and interests were. This would lead to a more natural way to getting involved in the issues at the core of this work; first the reality, then its model. As any model is a simplification of a real world phenomenon, our model does not reflect the whole reality. We modeled medical reasoning from a view shaped by the motivation of investigating context use in medical diagnosis. So, essentially the parts of medical problem solving that can be related to context are our primary focus.

Figure 2.2 illustrates the correspondence between cognitive and physical activities of the reasoner. So, the observed behaviour of the reasoner is, in fact, a reflection of the logic underlying her cognitive activities. However, not all cognitive activities trigger physical, observable activities. Cognitive activities require epistemological resources, while physical ones need physical resources. The analysis of these resources for each activity in either the ‘mental world’ or the ‘physical world’ provides us a basis for explicating and typing various contextual elements used in medical intelligence.

Medical diagnosis is an intelligent process as well as a practical art or skill. “As an intellectual discipline it engages in inquiry, formulates hypotheses and tests hypotheses, offers explanation, confirms hypotheses, and direct practice in accordance with scientific theories” [Albert 88]. So far in this chapter, we took an informal look into the logic of medical reasoning, as well as its intuitional aspects. In the rest of the chapter we investigate these aspects of diagnosis from a more computational view where we look into a model diagnosis in a more formal way.

![FIGURE 2.2 Reasoning and action are inter-weaved in a diagnostic process. Ellipses illustrate the cognitive actions and the squares show the actions in the real world.](image)
2.5 Accounts of the differences between novice and expert diagnosticians

Instructional research dealing with the development of new medical curricula explored new ways of teaching medical practice 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 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 knowl-
edge organization\textsuperscript{1} 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”\textsuperscript{2}.

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 correspondence in the context at learning and remembering time. We elaborate encoding specificity theory in chapter 7.

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 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.

2.5.1 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{3} process.

\textsuperscript{1} By knowledge organisation we will understand knowledge content including its structure.

\textsuperscript{2} Due to Minsky and Papert (1974), referred to in [Glaser 88]

\textsuperscript{3} 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 3, 4, and 5.
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.

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. 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). Consequently, the role of experience, its influences on organization 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.

2.5.2 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 used 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. 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 “pattern recognition” model of clinical reasoning 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. 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 makes experts capable of using 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 our interpretation of the relationship between hypothetico-deductive and pattern-recognition models.

2.5.3 The relationship between the hypothetico-deductive and the pattern-recognition models

An aspect which has been less explicated in both the hypothetico-deductive and pattern recognition models is that both require a “hypotheses generation” 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. Experts accomplish ‘hypothesis generation’ by employing a pattern recognition method while novices a hypothetico-deductive method.

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 reasoning 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.

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.
2.6 Accounts integrating process and content

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 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.

A recent approach investigates the characteristics of medical expertise via studying the process of development of expertise ([Schmidt 90]; [Schmidt 93]; [Boshuizen 95]; [Custers 96]). Content is the keystone in this approach. For example, Schmidt et. al. concentrated on the domain specific knowledge and medical experts’ organisations of knowledge bases. They have 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 will see in the following section.

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.

2.6.4 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 lengthy 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 biomedical 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 collegue’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”.

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

1. The terms biomedical knowledge and core domain knowledge are used interchangeably throughout the thesis.
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 organised. 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.

2.6.5 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 articulate 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 2.3 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.

**FIGURE 2.3** The correspondence between the components of medical reasoning model and AI model of expertise.
Our computational model of diagnostic process, elaborated in later chapters, suggests a combination of pattern recognition and hypothetico-deductive approaches, where the knowledge content of the knowledge based system determines the details of this combination.

2.7 Teaching Medical expertise

“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 subjects: 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 in medicine includes anatomy, biochemistry, physiology, microbiology, histology and pathology. Heated discussions are centered around questions of which type is more important for problem solving performance, and which sequence these should be taught, or should they be taught simultaneously.

2.7.6 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].

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1. We call ‘basic science knowledge’ as ‘core domain knowledge’ in later chapters.
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...”

2.7.7 The roles of biomedical and clinical 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 Talmont, 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.

1. Md Ole Rosvol, cardiology, RIT, Trondheim
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].

2.7.8 Problem Based Curriculum

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.

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.
4. 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]. 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 learning time if it is to be remembered at the same setting [Neame 84, p34].

According to Barrows and Tamblyn [Barrows 80], the role of group discussions is that the students explicate 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 subjects while “poor learners” generate insufficient explanations. The role of explanations has been emphasized also in AI. In chapter 10 we elaborate how the role of explanations are emphasized in the framework of the Creek system [Aamodt 94].

2.8 Conclusion

The lessons we have learned from the literature on medical problem solving and instructional research literature help us to understand the requirements for a knowledge base system that supports human medical diagnosticians.

Domain specific knowledge is a characteristic of a quick and high quality diagnosis. Domain specific knowledge includes both biomedical and contextual knowledge, packaged together. 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.” [Ericsson 91]. 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.

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.

The network-like structure of knowledge embodies explanatory knowledge which is resorted to when atypical cases are encountered by experts, and more often by less experts. So, both script-type knowledge and network-like knowledge are need to be captured in a knowledge based system. In this thesis a hybrid explanation-based case-based ([Kolodner 93]; [Aamodt 94b]) system is designed that comprises both biomedical and contextual knowledge.

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. 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.