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ABSTRACT

In two studies, the role of biomedical knowledge in the diagnosis of clinical cases by physicians and medical students was explored. Experiment 1 demonstrated a decrease in the use of biomedical knowledge with increasing expertise. This result appeared to be at variance with some findings reported in some but not all of the literature. In Experiment 2, three possible explanations for this phenomenon were investigated: rudimentation of biomedical knowledge, inertia, or compilation. Using a combined think-aloud and post-hoc-explanation methodology, it was shown that experts have more in-depth biomedical knowledge than novices and subjects of intermediate levels of expertise, but use this knowledge in a tacit way, the result of a process of knowledge compilation. The findings generally support a three-stage model of expertise development in medicine: (1) during the preclinical stage biomedical and clinical knowledge develop separately with an emphasis on biomedical knowledge; (2) during the clerkship stage, emphasis is shifted toward the acquisition of clinical knowledge; and (3) after both knowledge bases have matured to a sufficient extent, biomedical knowledge is compiled and integrated into clinical knowledge. Contains 30 references. (DB)

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The role of biomedical knowledge in clinical reasoning by experts, intermediates and novices

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THE ROLE OF BIOMEDICAL KNOWLEDGE IN CLINICAL REASONING BY EXPERTS, INTERMEDIATES AND NOVICES[1]

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ABSTRACT

In two studies, the role of biomedical knowledge in the diagnosis of clinical cases was explored. Experiment 1 demonstrated a decrease in the use of biomedical knowledge with increasing expertise. This result appeared to be at variance with some findings reported in the literature (e.g. Lesgold, 1984), but supported those of others (e.g. Patel, Evans and Groen, 1989).

In Experiment 2, three possible explanations for this phenomenon were investigated: Rudimentation of biomedical knowledge, inertia or compilation. Using a combined think-aloud and post-hoc-explanation methodology, it was shown that experts have more in-depth biomedical knowledge as compared with novices and subjects of intermediate levels of expertise, but use this knowledge in a tacit way, being the result of a process of compilation. The findings generally support a three-stage model of expertise development in medicine.

INTRODUCTION

As early as in the 15th century, physicians and other students of human biology tried to peer into the "black box" of the human body. People such as Antonio Benivienis (1448-1502) and Jean Fernel (1506-1588) attempted to relate their clinical observations to pathological-anatomic findings obtained from postmortem obduction. Eustachius (1524-1574), Fallopius (1523-1574) and Fabricius ab Aquapendente (1547-1619) described many organs and other structures in the human body, whereas Harvey (1578-1657) discovered blood circulation. After the development of the multi-lensed microscope (Van Leeuwenhoek, 1632-1723) the structure of the body and its physiology could be studied in more detail. Through the efforts of these investigators, the secrets that were kept safe in the "box" were discovered.

It was not easy to carry out these investigations in those days. Tools were not as sophisticated as they are now. Corpses were scarce, as only criminals sentenced to death were allowed to be anatomized. Only in winter a complete anatomic investigation of a corps could be carried out. However, since the days of Boerhaave (1668-1738) the biomedical sciences such as anatomy and physiology are considered crucial to the clinical sciences. Research into the structure and functioning of the human body has provided an increasing insight in its normal functioning and in the way disturbances of its equilibrium occur and are restored. Due to these research efforts, the mechanisms underlying long known empirical rules of thumb became understood and medicine developed : .. an art into a modern science. In particular since the beginning of this century, the biomedical sciences play an increasingly important role in the medical curriculum.

Notwithstanding its importance for medicine as a science, the role of biomedical knowledge in medical diagnosis and treatment in everyday practice is not at all clear. Research findings are contradictory and a theory on the structure of medical knowledge that could account for these diverging research outcomes is still lacking. The aim of the studies to be presented here was to investigate the role of biomedical knowledge in clinical reasoning at different levels of medical expertise, in an attempt to reconciliate opposing views. First, however, the role of knowledge in medical diagnosis will be discussed and studies addressing the issue of biomedical knowledge and clinical reasoning will be reviewed.

Medical diagnosis

Cognitive theories on medical diagnosis, as opposed to e.g. categorization theories or social interaction theories, assume diagnosis to be a process of comprehension and/or problem solving. In these theories, "mental representation of the problem" (or "problem representation") is a key concept. This position is elaborated by Feltovich and Barrows (1984). They define problem representation as ".... a cognitive structure corresponding to a problem (which is) constructed by a solver on the basis of domain related knowledge and its organization." The problem representation is "the solver's internal model of the problem, containing the solver's conceptions of problem elements, their relationships to each other, the goals of problem solving, etc." (Feltovich and Barrows, 1984, p. 132. See also Chi, Feltovich and Glaser, 1981). According to these authors, the representation of a diagnostic problem takes the form of an (instantiated) "illness script" in which patient characteristics, signs and symptoms of the disease, and knowledge of underlying processes are organized. These illness scripts describe the patient's present condition and how it came to be, understood through biomedical knowledge, knowledge of anatomy, physiology, pathology, pathophysiology, microbiology and pharmacology. In their view, biomedical knowledge puts constraints upon the ways patient characteristics, signs and symptoms are related.

It is this hypothesized role of biomedical knowledge that plays a central role in the discussion to follow. Feltovich' and Barrows' position in this debate can be paraphrased as: Comprehension, and hence the diagnosis, of a case emanates from biomedical knowledge. Their point of view is supported by other investigators in the domain of medical diagnosis (e.g. Lesgold, 1984; Kuipers & Kassirer, 1984; Kuipers, 1985; Lesgold, Rubinstein, Feltovich, Glaser, Klopfer and Wang, 1988). These authors all emphasize the role of biomedical knowledge in medical reasoning.

This perspective on diagnostic reasoning, however, is challenged by Patel, Evans and Groen (1989), and others (e.g. Schmidt, Boshuizen and Hobus, 1988). These authors suggest that medical experts predominantly use *clinical* knowledge instead of biomedical knowledge to represent and diagnose a patient problem[2]. According to these investigators, the application of biomedical knowledge is in particular characteristic for *non-expert* reasoning.

Experiments on the role of biomedical knowledge[3]

Not only theories about the application of biomedical knowledge in medical diagnosis are conflicting; the same holds for the outcomes of research in this area. Some investigators find an extensive use of biomedical knowledge in expert clinicians (e.g. Lesgold, 1984), whereas others report virtual absence of references to biomedical knowledge in expert protocols (e.g. Schmidt, et al. 1988) In this section, these experiments will be reviewed in some detail.

Many of the experiments in this domain have been conducted by Patel and Groen and their colleagues in Montreal, Canada (Patel and Groen, 1986a, 1986b; Patel, Arocha and Groen, 1986; Patel, Evans and Chawla, 1986; Joseph and Patel, 1987; Kaufman and Patel, 1988).

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[2]Clinical knowledge is defined here as knowledge of attributes of sick people. It concerns itself with the ways in which a disease can manifest itself in patients; the kind of complaints one would expect given that disease; the nature and variability of the signs and symptoms and the ways in which the disease can be managed. Biomedical knowledge by contrast, concerns itself with the pathological principles, mechanisms or processes underlying the manifestations of disease. It is phrased in terms of entities such as viruses or bacteria, in terms of tissue, organs, organ systems, or bodily functions.

[3]In this section, two types of research approaches common to the domain of clinical reasoning will be distinguished: On-line and post-hoc methods. On-line procedures attempt to "tap" the knowledge applied while the diagnostic process is in progress, whereas post-hoc methods are all based on a reactivation of the knowledge applied after a diagnosis is produced. Requiring subjects to think aloud while solving a diagnostic problem is an example of an on-line method. Asking subjects to explain the signs and symptoms of a case solved in terms of underlying pathophysiological processes is an example of a post-hoc method (Patel and Groen, 1986a)

Using a post-hoc method, Patel and Groen (1986b) presented beginning medical students, second, and fourth year students with a short case of a young man with a high fever and cold shivers. Furthermore, he had experienced a short loss of vision in his right eye the day before. A diastolic murmur over the aorta and puncture wounds in his left arm were found. Urinalysis showed numerous red cells[4]. Subjects were requested to state a diagnosis and to explain signs and symptoms in terms of underlying pathophysiological processes. In this study, only one subject, a fourth year student, arrived at the right diagnosis. All the other final year students' diagnoses were only partly correct, missing one or more components. About half of the first year students recognized the infection. In another experiment (Patel and Groen, 1986a), using the same acute bacterial endocarditis case with cardiologists, half of the diagnoses were right, while the others were only partly right. Hence, the case can be considered a fairly difficult one. It was found that the students' post-hoc explanations of the process causing the patient's signs and symptoms contained far more biomedical concepts than the cardiologists' explanations. However, the students' descriptions of the pathophysiological process were far more incoherent than those provided by the experts.

In a study reported by Patel, Evans and Chawla (1986), 24 subjects participated, with levels of expertise comparable to the Patel and Groen (1986b) study. Their findings replicated the earlier results: Diagnostic performance increased with an increasing level of expertise and more advanced subjects were better able to describe the case findings as a connected whole, and explain them coherently. Again however, more advanced subjects tended to use fewer biomedical concepts in their descriptions of what was happening to the patient presented.

In a study of Patel, Arocha and Groen (1986) only experts participated: Two cardiologists and two endocrinologists, half of them working in a clinical setting, half of them primarily involved in clinical research. They were presented with two cases, an endocrinology case

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[4] The patient in this case is suffering from an infection due to injections with contaminated needles. This infection turned into a sepsis resulting in an acute bacterial endocarditis with aortic insufficiency and infectious embolisms in the micro circulation. These components taken together form the diagnosis of the patient's disease.

(Hashimoto's thyroiditis with pre-coma myxedema) and a cardiology case (pericardial effusion with cardiac tamponade), resulting in a design in which practitioners' performance was compared with the performance of investigators on two cases: a case from their own specialty and a case from an unfamiliar specialty. As in the other experiments, they were asked to diagnose the case and explain the underlying pathophysiology. The results show that practitioners solving a case in their own domain of expertise used little or no biomedical knowledge to explain the case. On the other hand, when confronted with a case from the other domain, diagnoses were incomplete, while their pathophysiological explanations were more detailed. Researchers generally appeared to use more biomedical knowledge than practitioners.

Joseph and Patel (1987) utilized an on-line technique to investigate their subjects' representation of the same case of Hashimoto's disease as was used in the former experiment. Nine subjects participated, all physicians with five to ten years of experience. Four were endocrinologists (in this experiment called the 'high domain knowledge group') and five were cardiologists (the 'low domain knowledge group'). Case item presentation was computerized and the subjects were asked to verbalize their thoughts about the role and importance of each item presented in reaching the correct diagnosis. Joseph and Patel concluded that the high domain knowledge subjects' problem representations were more coherent. Detailed analysis of two protocols showed that a 'high domain knowledge subject' needed less information to generate a hypothesis than a 'low domain knowledge subject'. The 'low domain knowledge subject', working on a case from an unfamiliar specialty. activated more detailed biomedical concepts in order to interpret a set of case items than the 'high domain knowledge subject'.

In contrast to the experiments discussed so far, Kaufman and Patel (1988) required subjects to diagnose a real patient. This patient was a 22 year old oriental male who presented with two episodes of severe muscle weakness and other manifestations. He was diagnosed as suffering from Grave's thyrotoxicosis, a disease caused by two pathological states: Hyperthyreodism and hypokalemia. Subjects were five endocrinologists, five senior residents and five final year medical students. These subjects interviewed and examined the patient, provided a diagnosis and explained the process underlying the case. The experts were completely accurate in four out of five cases. Three out of five intermediate subjects attained the correct diagnosis. The other two did not notice the episodes of muscle weakness and hypokalemia. None of the undergraduate students provided an accurate diagnosis, but four out of five were right with respect to elements of the case. Elsewhere (Patel, Evans and Kaufman, 1989), it is reported that the experts' causal explanations generally, constituted coherent models for the stated diagnosis. Furthermore, the intermediates' explanations of the case were more detailed than the experts' and contained more biomedical concepts. Their explanations contained more inaccuracies as well. Finally, the novices' explanations contained many flaws and inaccuracies, often seemingly due to misconceptions.

The results of these experiments by Patel and her colleagues suggest a rather complex relationship between the outcome of the diagnostic process and the knowledge their subjects applied, as deduced from the post-hoc pathophysiological explanations of the cases. Novices construct incoherent representations of problems presented to them and make factual mistakes when describing the processes underlying a case. On the other hand, the less the actual clinical experience of the subjects, the more they tend to use biomedical concepts in their explanations. Clinical experts, diagnosing cases in a familiar domain appear to apply less biomedical knowledge than clinicians in an unfamiliar domain, clinical researchers, or intermediate level students.

However, differences in amount of biomedical knowledge applied, as found in the studies reviewed are not always easy to interpret, because in two out of the three studies involving students, extra information concerning relevant biomedical concepts was provided. In the Patel and Groen (1986b) experiment, the students first read three texts about relevant biomedical subjects (microcirculation, physiology of fever and human hemodynamics) before diagnosing the acute bacterial endocarditis case. This part of the experimental procedure may have affected the level of detail and the nature of the concepts applied in the pathophysiological explanations provided by the students, which might account for the observed differences between experts and students.

On the other hand, in a study by Schmidt, et al. (1988), using a more rigorous methodology, the same phenomenon was found. These authors replicated the Patel et al. studies using the same bacterial endocarditis case and 40 subjects of five levels of expertise, but did not provide the additional biomedical texts. They quantified their data by counting the number of biomedical propositions applied in explaining the pathophysiological process underlying the case and found an inverted U-formed relationship between level of expertise and number of biomedical propositions applied: Fourth and sixth year medical students produced more propositions of a biomedical nature than laypersons and second-year students. The experts however, produced the smallest number of biomedical propositions.

It is important to note that in most of the investigations discussed so far a post-hoc method was used. The remainder of this section will be dedicated to studies using an on-line approach to diagnostic reasoning.

Lemieux and Bordage (1986) were interested in differences in knowledge structure that might account for performance differences among students. They compared nine medical students --circumscribed as novice clinicians-- who had just completed a neurology systems block and who were identified by their teachers as either poor (n= 4) or outstanding (n= 5). One neurologist participated in the study to provide a point of reference. The subjects were presented with a case description of a patient suffering from cervical arthrosis: A 63 year-old man, complaining about numbness in the right arm for the last four months, mainly in the hand. Lemieux and Bordage asked their subjects to think aloud while solving the case. Their results showed that the outstanding students applied elaborate biomedical knowledge, whereas the poor students either applied unrelated lists of facts, or missed the relevant knowledge. The expert think-aloud protocol was far less detailed in terms of biomedical concepts than the outstanding students' protocols.

Lesgold and his colleagues (Lesgold, 1984; Lesgold, Rubinstein, Feltovich, Glaser, Klopfer and Wang, 1988) investigated the development of expertise in diagnosing X-ray pictures. Their first concern pertained to the way formal, biomedical knowledge is turned into a flexible diagnostic tool. They assumed that "the radiologist's knowledge of anatomical structure themselves is contained in a set of schemata to which many of the film features can be bound (Lesgold et al., 1988, p. 320)." Functioning, tuning, flexibility and accuracy of these schemata at different stages of development was the main issue of their research, not the amount and detail of biomedical knowledge applied in problem solving. Notwithstanding that, their results provide some insights relevant to the aims of the present article.

Lesgold et al. (1988) explored the relation between diagnostic outcome and characteristics of the knowledge applied. These investigators asked junior and senior residents in addition to experts in radiology to describe and diagnose several chest X-ray films, highly reflecting the subjects' daily work. Requiring subjects to describe such an X-ray film can be considered an on-line method to investigate the subjects internal representation. Lesgold et al. found clear differences between subjects in terms of structures attended to and concepts applied while describing the X-rays. Experts and intermediates applied many terms pertaining to the anatomical location and to the hypothesized pathology while describing the film. On the other hand, the terminology used by the novices generally was of more global nature. They often did not mention a possible pathological state, and anatomical structures were referred to only in vague terms. These findings suggest that with increasing level of expertise, biomedical knowledge applied is more detailed and more tailored to the case at hand.

Feltovich, Johnson, Moller and Swanson (1984) investigated the relation between level of expertise and the structure of the knowledge applied utilizing an on-line approach. Twelve subjects of different levels of expertise in pediatric cardiology participated: Four pediatric cardiologists, four residents specializing in pediatric cardiology and four students who just finished a six-week elective course on the subject. Feltovich et al. presented four case descriptions including an X-ray film of the thorax and an ECG. Items were presented on cards in a sequential fashion. It was the subjects' task to read aloud all the case findings and to verbalize everything that crossed their mind while diagnosing the case. Cases were selected such as to optimize the investigation of differences in sets of diagnostic hypotheses considered, and the ways in which case findings determining the diagnostic choice were combined. In order to do so, Feltovich et al. compared their subjects' "diagnostic path" with an ideal diagnostic path. Their results indicated that the students' knowledge structure resembled the text book structure. Students applied the same set of hypotheses as clustered together in text books typically used in the domain of study, and assumed the same prototypical characteristics of a disease. In experts, no such organization could be found. Feltovich et al. concluded that with an increasing level of expertise, knowledge structures pertaining to the mutual relations between diseases change. Student knowledge structures are apparently organized in hierarchical fashion, reflecting the text book organization (e.g. cyanotic and non-cyanotic congenital heart diseases). Furthermore, they concluded that in the expert group this strict hierarchy is broken, while new links between disorders with the same underlying pathophysiology and symptomatology appear. These differences in knowledge and knowledge structure are expressed in hypotheses considered and in the final diagnosis . In a paper by two other investigators from this group (Hassebrock and Prietula, 1986), a more detailed description can be found of the knowledge applied by subjects of varying levels of expertise while diagnosing a congenital heart disease. From the protocol segment samples they report, it appears that novices applied elaborate biomedical knowledge but failed to activate specific disease defects that could cause the patient's symptoms. Experts, on the other hand, did not have to 'reason through' a biomedical conceptual network in order to activate a relevant diagnosis, but instead recognized specific findings as indicative of a general class of cardial defects.

---------------------- **Insert Table 1 about here** ------------------

The experiments reviewed, are summarized in Table 1. As can be seen in this overview, the methodology applied, the nature of the cases presented, the levels of expertise studied, and the conclusions are highly diverse. The most striking differences are found between the studies of Patel and her colleagues and those of others. Patel et al. used a post-hoc methodology in five out of six investigations, whereas in the other studies on-line methods prevail. In addition, the Schmidt, et al. (1988) study, which generally, replicated and extended the Patel findings, also used a post-hoc approach to studying the role of biomedical knowledge in medical problem-solving. One is tempted to conclude that the contradictions among findings may be due to differences in methodology. However, the Patel findings are at least partially supported by on-line studies by Lemieux and Bordage (1986) and Hassebrock and Prietula (1986)[5].

Some of the studies suggesting a major role of biomedical knowledge in medical expert diagnosis, on the other hand, provide only circumstantial evidence for this proposition. This is particularly the case with the Feltovich, et al. (1984) study. The studies of Lesgold and colleagues however, provide unequivocal support for the thesis that the development of expertise in medicine is characterized by an increasingly flexible and more adequate use of biomedical concepts. Their experts clearly showed signs of deeper understanding of the nature of the disease, and this understanding was based on more elaborate schemata consisting of anatomical and pathophysiological concepts. This may, however, be an idiosyncratic property of the radiology domain[6].

In conclusion, the experiments reviewed do not provide a sufficient basis to decide whether biomedical knowledge plays a major role in expert diagnosis, and if so, *how* this role is played. Nor can major conclusions be drawn about its role in preceding stages of the developmental path. Our first and tentative conclusion therefore, is, that the overt application of biomedical knowledge decreases with increasing level of expertise (perhaps with the

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[5] However, Hassebrock and Prietula did not quantify their data and only provided examples. Lemieux and Bordage's conclusions are based on quantitative data (they counted the number of intermediate concepts in a line of reasoning), but they compared students of a rather advanced level and one expert.

[6] The domain in which Lesgold et al. conducted their research; diagnosis in radiology, is rather exceptional. Radiology cases are not patients complaining about something, but pictures of these patients' insides, providing a direct, although distorted, image of the black box that remains closed to physicians in most specialties. Radiologists actually *see* their patients' lungs or gallbladders, and the pathological changes that have occurred in these organs. To radiologists, biomedical concepts provide the main instrumentarium to describe what is seen. In other medical domains, the physician must construct a mental image of organs and disturbances based on the signs and symptoms the patient presents. In these specialties, the distance between the information provided to the doctor and the biological substrate may be much larger than in radiology.

exception of those domains in which the diagnostician has "direct access" to the organic disturbance as in radiology or surgery). In addition, it is suggested that in the course of development, biomedical and clinical knowledge are subject to changes, both in structure and function. It is however unclear through which mechanisms these changes are induced.

In order to further investigate the role of biomedical knowledge in medical diagnosis, two experiments were carried out. The first experiment was exploratory in nature. Four subjects of different levels of expertise were extensively studied while reasoning about a case presented to them in a sequential fashion. The purpose of this on-line study was to clarify the role of biomedical knowledge in clinical reasoning and to suggest hypotheses about the possible mechanisms responsible for changes in the course of development. In the second experiment, these hypotheses were tested in a population of twenty subjects differing in expertise.

EXPERIMENT 1

Method

Four subjects at different levels of medical expertise participated in the study: One second-year medical student; a fourth-year student who had nearly finished his preclinical training; a fifth-year student who had finished both a primary care and an internal medicine clerkship, and a family physician with four years of experience. The second year student was the 'Novice' in this study. The fourth and fifth year students were 'Intermediate-1' and 'Intermediate-2'. And the family physician was the 'Expert'.

The subjects were presented with a case of a 38 year old, unemployed male with a history of neurotic depressions and alcohol abuse. One year earlier, this patient had an attack of pancreatitis, and now calls the family physician with a complaint of severe, boring pain in the upper part of the abdomen. He suffers from a chronic relapsing alcohol-induced pancreatitis with minor pancreatic insufficiency. The symptoms associated with this disease and the underlying pathophysiological mechanism are described in Table 2. The case was presented on 48 typed cards, each containing one or more items of information which characterized the patient, history taking, physical and lab findings (the case items are represented in the left column of the Appendix).

The subjects were asked to think-aloud while being presented with the cards in a sequential fashion and to provide a differential diagnosis at the end. These sessions were tape recorded and verbatim transcripts were produced.

-------------------- **Insert Table 2 about here** --------------------

Analysis

Think-aloud protocols

The analysis of the think-aloud protocols aimed at the identification of those parts of the protocols in which biomedical and clinical knowledge were applied to diagnose the case. The identification of these parts was achieved in a step by step approach. The first step in the analysis of the think-aloud protocols was a rough segmentation based on pauses in the protocols. Next, segments containing more than one single 'basic conceptual operation' (e.g. generate a new hypothesis or verify an existing hypothesis) were further subdivided, thus each protocol segment may be assumed to represent one basic conceptual operation. Examples are protocol segments, such as ".. May have to do with the gall bladder" (a hypothesis generation segment), "Now I want to know the time of onset, severity, character of the pain, etc." (a segment in which a need for further information is expressed in response to the item describing the patient's complaint), "I would leave this point aside and first concentrate on ..." (a planning segment), or "I would never have asked that question!" (a segment commenting on the kind of information that is provided in the case description). Subsequently, all segments pertaining to goal management and information need were excluded from the analysis as were segments pertaining to the perceived quality of the resulting problem representation (e.g. "I am not sure whether what I am saying now is really right").

By doing so, a protocol-framework remained, consisting of segments in which a case finding was linked to an interpretation, one or more case findings were linked to a hypothesis (or vice versa) or in which two hypotheses were linked.

These remaining segments, represented as propositions consisting of (at least) two conceptual entities and a relation, were represented as semantic networks. In these semantic networks the temporal order in which these propositions emerged in the think-aloud protocols was maintained (an example of such a protocol-framework is given in the Appendix). In these networks, biomedical propositions were distinguished from non-biomedical propositions[7]. Criterion for this distinction is the object of the proposition. Propositions concerning pathological principles, mechanisms or processes underlying the manifestations of disease are classified as biomedical propositions. They are phrased in terms of entities such as viruses, bacteria, stones or carcinomas; in terms of tissue, organs, organ systems, or bodily functions. 'Irritation of peritoneum indicates diminished intestinal motility' is an example of such a proposition. By contrast, propositions concerning attributes of people, including their diseases, are labeled non-biomedical (Patel, Evans and Groen, 1989). These propositions are concerned with the ways in which a disease can manifest itself in the patient; the kind of complaints one would expect given a specific hypothesis; the nature and variability of the signs and symptoms and the ways in which the disease can be managed.

As the classification principle is based on the object of a proposition, often propositions from adjacent protocol fragments must be taken into account. The propositions were extracted and classified by two independent raters; whenever necessary, agreement was attained after discussion. The biomedical propositions were counted and this number was divided by the total number of extracted propositions.

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[7] It should be noted that this classification biomedical - non-biomedical corresponds to the classification biomedical - clinical. In the way our classification system worked out non-biomedical was the default category. Hence, as far as the protocol analysis is concerned, the more technical term 'non-biomedical' is preferred.

Two illustrating examples

Segmentation of the protocols and segment characterization are illustrated in the following protocol parts, generated by the four subjects in response to two items of the case. The protocol statements are subdivided into segments separated by: "||"; repetitions of case information are placed between brackets: "()"; the knowledge application parts are underlined; indications of information need are italicized.

In Table 3 the reactions of the subjects to the complaint (Item 8) are shown. The complaint is always very important in clinical thinking, but in this case it is not at all unique to the disease at hand. In order to arrive at a diagnosis both information about the patient's personal and medical history and alcohol abuse are needed as well as information about other signs and symptoms. In the Novice's protocol two segments are identified; one of these is a knowledge application proposition. In the other segment, the subject indicates that he can not do very much with a part of the information. The two segments in Intermediate-1's protocol both can be classified as knowledge application propositions. Intermediate-2 responds to this item in two segments; in one of these he relates the complaint to previous information and in the other he expresses his wish for further information. The Expert's protocol can be subdivided into seven segments. In the first segment the information given is clustered together, which results in the activation of five hypotheses. In the final segment the meaning of one term is questioned.

------------------- **Insert Table 3 about here** --------------------

In Table 4 the subjects' responses to Item 20 are shown. In this item, information is provided that the patient has been depressed since ten days. Furthermore, it is told that the patient tried to commit suicide by taking six tablets of Mogadon (a benzodiazepine), together with a high amount of alcohol. This information is very important for a physician. On the one hand it indicates that the patient has again mental problems, maybe in combination with a somatic disease. On the other hand, a large drinking bout may result in an attack of pancreatitis 48 hours later.

The Novice's response can be subdivided into six segments. Two of these segments can be categorized as knowledge application propositions. In the remaining segments the subject indicates that he would like to know more about the information provided, and indicates his lack of knowledge about Mogadon. In Intermediate-1's protocol three basic mental operations can be counted. Two of these were classified as knowledge application propositions. The other segment has an evaluative character. In Intermediate-2's protocol we find four segments, with two propositions. In one segment, previous and present information are compared. In the final segment Intermediate-2 indicates his need for further information about this item. The Expert's protocol part reported here[8], can be divided into 12 segments; four of these were identified as knowledge application propositions. In all these propositions clinical knowledge concerning the patient is applied. The Expert expresses his need for further information in the other segments, by asking where the Mogadon came from and how the patient's environment had reacted. Furthermore, he elaborates on these self-generated questions. In one large segment this subject plans his approach to this patient: first he wants to be sure about the somatic aspect, but the mental part may not be ignored.

---------------------- **Insert Table 4 about here** -------------------

About half of the segments in these examples are knowledge application propositions; none of these were classified as biomedical propositions. All these propositions are part of the resulting framework, after the other segments --in which information is scrutinized, clustered and elaborated, plans are developed or lack of knowledge is expressed-- were removed.

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[8] This protocol part is abbreviated. In fact, the Expert's protocol contained 3 more segments, concerning a previous item.

Results

Characteristics of the think-aloud protocols

The four think-aloud protocols largely varied in elaborateness (See Table 5). The longest protocol was produced by the Expert. His protocol consisted of 256 basic mental operations, from which 78 knowledge application propositions could be extracted. Intermediate-1's protocol was the shortest, consisting of 120 basic mental operations, including 71 propositions. The other students' protocols were closer to this extreme. Intermediate-2's protocol consisted of 135 basic mental operations and, though not the shortest of the four, less propositions (39) could be extracted from this protocol than from the others'[9]. The Novice's protocol contained 160 operations, including 75 propositions. As we have only one subject per level of expertise, it is impossible to decide whether these differences are characteristic for the experimental subjects or whether they are related to group differences. The number of biomedical propositions that could be identified in these sets of knowledge application propositions was not proportional to the total number of propositions: The protocols of the two subjects of a lower level of expertise contained more biomedical propositions than the other two protocols (42 and 24 vs. 7 and 5).

---------------------- **Insert Table 5 about here** -----------------

Application of biomedical knowledge

Since the total number of knowledge application propositions produced varied between subjects, proportions of biomedical propositions per subject were computed. The proportion of biomedical propositions extracted is represented in Figure 1. As can be concluded from this graph, the proportion of biomedical propositions in the set of propositions extracted decreases with increasing level of expertise. More than 50% of the second year student's propositions were labeled as biomedical, monotonically decreasing to less than 10% in the Expert's proto-

[9] This subject's protocol consisted to a relatively large extent of segments pertaining to planning, goal management and information clustering without an interpretation was made.

col. This result by and large replicates the findings reported by Patel and her colleagues, and suggests that the overt role of biomedical knowledge in the development of a mental representation of a medical case decreases with an increasing level of expertise.

------------------- **Insert Figure 1 about here** -------------------

A qualitative analysis[10] of the propositions extracted from the think-aloud protocols shows, however, that the quality of the applied biomedical knowledge changes over time. In the Novice's protocol many chains of propositions are found containing invalid concepts or relations.

An example of the application of an invalid concept is the chain of propositions found in response to Item 23, that according to other people the patient has been jaundiced once in a while during the last time.

Novice: ".. errm well that suggests a <u>liver disease</u> ||.. err .. in which case .. er.. <u>pirubin*</u> I believe can cause (yellowing of the skin) ..|| "[11].

In this chain the concept 'pirubin' was applied to explain the case finding of 'yellowing of the skin'. It is a corruption of 'bilirubin', which is produced in the liver.

An example of the application of an invalid relation can be found in the chain of propositions in the response to Item 48a, the high level of serum amylase. Here the Novice states: ". So that's a <u>considerable elevation || amylase, that's starch*</u> I believe . .err .. || yes so probably he will .. is <u>still troubled with those complaints of his pancreas*</u>,|| resulting in a ..err.. <u>decreased breakdown of starch into ..er.. glucose*</u> || .... resulting in an <u>increase of starch*</u> || . err.. well yes then you you're thinking of <u>beta cells producing insulin*</u> ||."

In the second proposition of this chain the Novice identified the enzyme amylase with starch, the nutricious element that is digested with the help of amylase.

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10 The authors wish to thank P. P. M. Hobus for this.

11 Segments and features of propositions are marked in the same way as was done in Tables 3 and 4, furthermore, the application of biomedical knowledge is indicated with an asterisk, '*'..

No such obvious mistakes and misconceptions occurred in the other subjects' protocols. Hence, the relative share of biomedical propositions in the total number of knowledge application propositions diminished with an increasing level of expertise, while the quality of the biomedical knowledge applied was better in the higher levels of expertise.

Another striking phenomenon concerns Intermediate-1's style of reasoning, a style which is not encountered in the other subjects' protocols. This style can be characterized as a detailed, step by step approach from the case signs and symptoms to the final diagnosis. A typical example of such a line of reasoning was found in the response to Item 34, the patient's pulse rate.

Intermediate-1: "... er . yes . (the past two .) together . mean that there's err no inflammation * || .. and that would eliminate an , er .. an ..er. cholecystitis || .. and would rather mean an . er ... obstruction of the biliary tract * || . caused by a stone*, for instance || . or, what may be the case too, by a carcinoma* || but I wouldn't .. although, it might be possible: (lost 5 kilograms in weight)..||"

In this chain of propositions Intermediate-1 first concluded from the patient's normal temperature and pulse rate that there is no inflammation and hence no cholelithiasis. Then he wondered what other kind of process could cause biliary tract obstruction, his main hypothesis. As a first solution, a stone was thought of, but a carcinoma was considered as well. Confirming evidence for this last possibility was found in the patient's weight loss. Remarkably, four of the six propositions in this chain contained biomedical concepts (inflammation, obstruction of the biliary tract, stone and carcinoma).

Noticeably, this approach differs from the Expert's approach, which is far less detailed. More than any other subject the Expert took the patient's background into account in generating and verifying or falsifying hypotheses. For example, in response to Item 29 concerning the patient's weight loss in the past six months the Expert stated:

"... (The past six months), that's an important piece of information; || it err .. can lead two ways; || it's an er .. (he's a drinker the past six months,)(before that too a heavy one). (eats irregularly),(err eats . has a poor appetite). all reasons to er, (what food he takes seems a bit deficient, judging from what he describes), so it may be quite possible that his food intake is insufficient on the one hand; || he is in the side of (he has had an acute pancreatitis in the past), (a drinking habit), (fatty liver), erm. (He's only er... he's in his thirties) .. he's suffering from an .. of course it might be a manifestation of a process in the liver || or a malign process in the pancreas; || two tracks remain open from this information.||"

Based on information about the patient's mental history he concluded that either the patient's weight loss may be caused by insufficient food intake or by a malignancy, although the patient is only in his thirties (and hence rather young for such a disease). Traces of this kind of reasoning were also found in Intermediate-2's protocol. For instance in response to the same item he says:

" . Oh yes, (but he has been drinking again of late); ||"

Taken together these results indicate a marked shift from the application of biomedical reasoning toward the application of clinical knowledge. In this study, the transition from the application of biomedical knowledge to the application of clinical knowledge seems to be associated with the transition from pre-clinical to clinical work and studies. Hence, practical experience might play an important role in this change.

Discussion

The results presented so far are in agreement with findings by Patel and her colleagues (Patel and Groen, 1986a; 1986b; Patel, Evans and Chawla; 1986; Patel, Arocha and Groen, 1986; Joseph and Patel, 1987; Kaufman and Patel, 1988), who showed that increasing levels of expertise are associated with a decreasing application of biomedical knowledge. They speak against the findings of those researchers who claim an important role for biomedical knowledge in expert clinical reasoning (Lesgold, 1984; Lesgold, Rubinson, Feltovich, Glaser, Klopfer and Wang, 1988; Feltovich, Johnson, Moller and Swanson, 1984) In addition, a peak in the functionality of the biomedical knowledge applied was observed at the lower intermediate level, whereas after this stage in development the application of clinical knowledge appeared prominent in the protocols. These results suggest that biomedical knowledge is acquired and used as the major instrument in interpreting clinical information in the early stages of development. After misconceptions have been removed, biomedical knowledge provides a reliable tool for forming a coherent mental representation of a clinical case. However, this application of biomedical knowledge seems to characterize a transient stage in the development toward expertise. The transition to the next stage seems to be initiated by the effect of practical experience. In this next stage, the application of biomedical knowledge seems to be virtually absent. Instead, clinical knowledge is predominantly applied.

The question arises: what happens to the biomedical knowledge at this stage of development? Several possibilities must be considered. The first possibility is that, in medical practice, biomedical knowledge is no longer needed and, hence, becomes forgotten and rudimentary. This opinion is sometimes expressed by expert practitioners, who realize that they appear to have forgotten much of what was presented to them in medical school. This phenomenon was documented in the domain of chemical and electrical engineering by Ackermann and Barbichon (1963). These authors found that after a prolonged period of experience in industry, engineers had forgotten a large part of their knowledge about the basic sciences in domains taught and mastered in college and at the university.

A second hypothesis is that biomedical knowledge may be still available but has become inert. In this case the knowledge would still be available, but is of such general nature that it is not activated in an application situation. Leinhardt (1987) has demonstrated such a phenomenon in the domain of teaching. In teacher education, mathematics is considered very important for teaching elementary arithmetic. This general, 'context-free, principled knowledge', as Leinhardt calls it, can be remembered for more than 20 years, but is not integrated in the experiential, situated knowledge of teaching elementary arithmetic. The same may apply to the domain of medicine. Instead of context-free, principled biomedical knowledge, clinicians may tend to use experiential knowledge, acquired as a result of extended practice and continuous exposure to the many different ways in which disease manifests itself.

A final hypothesis that must be considered, is that expert biomedical knowledge is actually compiled and integrated into clinical knowledge. According to Anderson's theory (1983, 1985, 1987) on the development of mental skills, at one stage of development elaborate knowledge (in this case biomedical knowledge) is applied in problem solving, resulting in a stage in which compiled knowledge is applied. In this latter stage, application of biomedical knowledge would be automatic, therefore leaving no verbal traces in the think-aloud protocols (Ericsson and Simon, 1984).

In order to investigate these three competing hypotheses Experiment 2 was conducted.

EXPERIMENT 2

In Experiment 2 three mutually exclusive hypotheses about the role of biomedical knowledge in medical diagnosis in successive levels of expertise were investigated;

a) After a certain stage in the development toward expertise biomedical knowledge becomes rudimentary. That is: Large parts of the expert's biomedical knowledge (especially detailed knowledge) are no longer available.

b) After a certain stage in the development toward expertise biomedical knowledge becomes inert. That is: Biomedical knowledge is still available to medical experts, but can only be activated when directly addressed.

c) During the development toward expertise biomedical knowledge becomes compiled and is integrated into clinical knowledge. That is: In clinical reasoning experts apply abridged knowledge, but this knowledge is directly linked to associated detailed, deep level knowledge which can be retrieved whenever necessary.

In order to test these hypotheses, both an on-line and a post-hoc technique were used. Comparisons between biomedical knowledge applied while diagnosing the case and post-hoc provided pathophysiological explanations were carried out. Whether biomedical knowledge has become rudimentary, inert or compiled, the think-aloud protocols are expected to show a decrease in the proportion biomedical knowledge applied, associated with an increasing level of expertise, as was found in Experiment 1. However, if biomedical knowledge has become rudimentary, a decrease in the elaborateness of the pathophysiological explanations provided post-hoc can be expected. Under this condition, experts may be less able to produce extensive accounts of the pathophysiological processes underlying the case as compared with intermediates. On the other hand, if biomedical knowledge has become inert, then there is no reason to expect that experts will produce shorter explanations than intermediates do, because the knowledge is available (albeit not used in clinical reasoning) and can be reproduced upon request. However, if biomedical knowledge is compiled and integrated in clinical knowledge, no prediction about the extent of the pathophysiological protocol can be made. It is hypothesized here that compiled knowledge can be differentiated from inert and rudimentary knowledge by inspection of the nature and the amount of overlap between the knowledge actually applied --as deduced from the on-line method-- and the knowledge genuinely available to explain the findings after completing the case. If expert biomedical knowledge is compiled, it is expected that an increasing level of expertise is associated with an increasing overlap of the content of the think-aloud protocols and the pathophysiological explanations. In case physicians only have an inert or rudimentary knowledge base, there is no reason to expect an increasing overlap associated with an increase in expertise.

Method

Subjects

In Experiment 2 twenty subjects participated. Six subjects were second year students, having the same level of expertise as the Novice in Experiment 1. Four subjects were of the same level of expertise as Intermediate-1, namely at the end of the fourth year. Five fifth year subjects (Intermediate-2 level) participated, who had finished their clerkships in internal and family medicine. The Expert group consisted of five family physicians with about four years of experience.

Material and Procedure

The subjects were presented with the same pancreatitis case as was utilized in Experiment 1. The subjects' task was to diagnose the case while thinking aloud. After completing the case they were asked to describe (in writing) the pathophysiological processes, that in their opinion, underlie the case. Subjects were tested individually.

Analysis

The think-aloud protocols were analyzed with respect to the application of biomedical knowledge. The same procedure was applied as used in Experiment 1. First, the protocols were divided into segments representing one basic mental action and propositions were extracted from these segments. These propositions were classified as biomedical or non-biomedical depending on the object of the proposition. Next, the amount of applied biomedical knowledge was determined by counting the number of biomedical propositions. One audio recording (of subject #5-12, a fifth year student) contained so much noise that no transcription could be derived from it. Therefore, analyses of the think-aloud protocols were based on the data of 19 subjects.

The explanations of the underlying pathophysiological process were analyzed utilizing a method described by Patel and Groen (1986a). Patel and Groen segmented these texts into propositions consisting of two concepts and a relation. These propositions were represented as a semantic network and their number was counted.

Finally the amount of overlap between the propositions derived from the think-aloud protocols and the propositions derived from the pathophysiological explanations was assessed. The amount of overlap was defined as the proportion of concepts in a subject's semantic network (derived from the post-hoc explanation) identical to any concept in the set of propositions derived from his or her think-aloud protocol.

Results

Think-aloud protocols

The number of biomedical propositions extracted from the think-aloud protocols, is associated with level of expertise ($F(3,15)= 4.102$, $p< .05$). However, as is shown in Table 6, individual differences in length of the think-aloud protocols (especially in the second year students and in the expert group) may play a role in these results.

-------------------- **Insert Table 6 about here** --------------------

In order to account for such an effect, the number of applied biomedical propositions was expressed as a proportion of the total number of propositions extracted from the protocols ($F(3,15)= 3.199$, $p< .06$). The results of this analysis are presented in Figure 2. Apparently, the top of the curve is to be found in the fourth year students group. About half of the knowledge they applied in the think-aloud protocols was derived from the biomedical sciences. Associated with this curve is a significant cubic component ($F(1,15)= 6.215$, $p< .05$). The linear and quadratic components of the curve have a p-value $> .10$.

These results confirm the finding that, contrary to intermediates, experts seem to apply hardly any biomedical knowledge. However, the monotonic decrease that was found in Experiment 1 could not be replicated.

-------------------- **Insert Figure 2 about here** --------------------

Post-hoc pathophysiological explanations

The number of propositions used to explain the pathophysiological process underlying the patient's complaints is associated with level of expertise ($F(3,16)= 3.567$, $p< .05$). Polynomial analysis shows that only a linear component in this relation is significant ($F(1,16)= 10.443$, $p< .05$, with no significant deviations from linearity ($p> .25$) (see Figure 3).

From this result it is concluded that the experts' biomedical knowledge certainly has not become rudimentary. On the contrary, an increasing level of expertise seems to be associated with a monotonic increase of knowledge of the biomedical sciences. These data clearly contradict the hypothesis that the use of biomedical concepts decreases with expertise because of these concepts becoming rudimentary or inaccessible.

-------------------- **Insert Figure 3 about here** --------------------

Amount of overlap

The two remaining competing hypotheses are in some way mutually exclusive. If biomedical knowledge becomes more and more compiled in the course of development toward expertise, then it is expected that the overlap between the biomedical knowledge actually applied while solving the case and knowledge applied post-hoc while explaining the case, will increase with an increasing level of expertise. If, on the other hand, biomedical knowledge becomes inert, then (maybe after an initial raise) this overlap will remain at a constant level or will even decrease. In order to investigate these hypotheses the propositions derived from the think-aloud protocols were matched against the semantic networks.

These analyses show that overlap increases monotonically with an increasing level of expertise ($F(3,15)= 19.887, p< .0001$). Among the novices, the amount of overlap was only 14.9%. This percentage increased to 56.2% in the expert group. The linear component associated with this trend is highly significant ($F(1,15)= 57.903, p< .0001$, with no significant deviations from linearity, $p> .25$). The results from the overlap analyses are represented in Figure 4.

-------------------- **Insert Figure 4 about here** --------------------

These results indicate that expert biomedical knowledge has not become inert. On the contrary, the conclusion seems justified that, while solving a case, experts apply knowledge about the biomedical sciences in a compiled fashion.

Discussion

In the introduction to this article, it was suggested that the conflicting research outcomes about the role of biomedical knowledge in clinical reasoning could perhaps be attributed to the research method applied. Investigators using a post-hoc approach to clinical reasoning (e.g. Patel, Arocha and Groen, 1986; Joseph and Patel, 1987), found that increasing levels of expertise were associated with a decreasing application of biomedical knowledge, whereas others, using the think-aloud methodology (e.g. Lesgold, 1984; Feltovich, et al., 1984) claimed that expertise predominantly is characterized by an extensive use of relevant biomedical concepts. However, the results of both experiments reported in this article, demonstrate that, even under conditions in which subjects are required to think aloud, medical experts appear to apply less biomedical knowledge than less experienced subjects. In this section, we will further elaborate upon the three possible interpretations that were suggested to explain this empirical result and the contradictions that reside in the literature.

Does biomedical knowledge become rudimentary?

The first interpretation offered was one in terms of the decay of biomedical knowledge previously acquired. According to this interpretation, biomedical knowledge may be useful at one stage of the intellectual development of physicians-to-be, for instance, because it may help in the initial understanding of clinical phenomena. But after being confronted with real patients and their diseases, biomedical knowledge becomes less important and may eventually become inaccessible or rudimentary. This interpretation would explain why the number of biomedical concepts used in think-aloud procedures was negatively associated with the level of expertise of our subjects. However, the post-hoc acquired protocols, in which the subjects explained the case in terms of underlying pathophysiological processes, clearly demonstrated that this interpretation is an unlikely candidate for explaining the findings, since we were able to show that experts actually had a more elaborate biomedical knowledge base than subjects of lower levels of expertise. This observation is confirmed by a qualitative analysis of the post-hoc explanations provided.

Only one out of the six novices applied biomedical concepts[12] to explain the pathophysiological process underlying the patient's signs and symptoms. This subject assumed that a kind of poisoning process caused the liver (or some other organ) to become inflamed. Among the fourth-year students two out of four subjects applied biomedical concepts to explain the pathophysiological process. One subject supposed that irritation of the pancreas can cause a tumor in the pancreas head, causing obstruction in the ductus choledochus which, in turn, would cause the bile to dam up in the liver, probably resulting in a diminished functioning of the liver. The other subject used concepts like 'slight intoxication' and 'lack of insuline'. In the group of fifth-year students, three out of five semantic networks produced contained biomedical con-

[12] The other subjects directly refered to symptoms of the patient or to a diagnostic label.

cepts to explain the pathophysiological process. One subject applied the concept of a changed pH in the stomach; another subject assumed that fibrosis of the pancreas causes a stricture of the ductus choledochus; while a third subject hypothesized two processes: Choledochus stenosis causing bile stasis, or autolysis of the pancreas by its own enzymes. By contrast, four or the five experienced physicians explained the pathophysiological process applying biomedical concepts. In the Experts' semantic networks concepts as 'destruction of tissue', 'release of pancreatic enzymes', 'diminished digestion', 'atrophy of the liver cells', 'atypical inflammation reaction', 'scarring of tissue', 'changed structure of the pancreatic duct', 'sensibilization for other toxic and physical influences' and 'deposit of metabolites' were found.

As can be concluded from these descriptions, not only the elaborateness of the pathophysiological explanations provided increased, as was illustrated in Figure 3, but the hypothesized process underlying the case and the canonical one, described in Table 2, became increasingly similar. Both findings indicate that the biomedical knowledge of our subjects expands with a increasing level of expertise.

Does biomedical knowledge become inert?

The second possible explanation for the relative absence of biomedical reasoning in the experts' think-aloud protocols was, that expert biomedical knowledge has become inert in the course of clinical practice. The knowledge is still available in long term memory, as shown by the results of the post-hoc measurements, but simply is not used anymore. Hence, experts would apply less biomedical knowledge in solving medical problems than intermediates. This would explain the apparent contradiction between the relative absence of biomedical concepts in the think-aloud protocols and their abundance in the post-hoc explanations. The results of Experiment 2, however, seem to contradict this interpretation as well. If biomedical knowledge is no longer active in the interpretation of clinical findings, there would be no reason to assume that concepts used in a post-hoc explanation of the case would also appear in the think-aloud protocols. Knowledge applied in clinical reasoning and biomedical knowledge would "represent two different worlds", with no relation whatsoever (Patel, Evans and Groen, 1989). In fact, however, an increasing overlap was found between biomedical knowledge available in the think-loud protocols and the knowledge produced in the post-hoc explanations. This finding suggests that experts' biomedical knowledge has not become inert, but actively is used in the process of understanding a clinical case, albeit in a somewhat tacit way.

Does biomedical knowledge become compiled?

Based on the increasing overlap of biomedical concepts produced in the post-hoc protocol and concepts used while thinking aloud, we proposed the hypothesis that expert biomedical knowledge has become compiled and integrated into the clinical knowledge applied when an expert diagnoses a case. The question, of course, is whether the phenomena observed in our subjects indeed are the result of a process of knowledge compilation, or whether alternative explanations are possible.

In the introduction to Experiment 2, it was assumed that students apply elaborate biomedical knowledge when diagnosing a case. According to Anderson (1983, 1985, 1987), such knowledge, consisting of a chain of propositions, is compiled into a rule connecting problem features, to which this knowledge applies, and the outcome of the problem-solving process. In clinical reasoning, this compilation mechanism may result in the combination of sets of symptoms and their associated diagnosis. This may explain both the decrease of biomedical propositions in the think-aloud protocols and the increasing overlap between biomedical concepts found in on-line and post-hoc protocols.

However, at least one other learning mechanism and, hence, one other relation between clinical and biomedical knowledge can be hypothesized as well. In this alternative explanation, it is assumed that biomedical and clinical knowledge develop as distinct knowledge bases. In the preclinical years of their training, students study topics from both the biomedical and the clinical disciplines. They learn about anatomy, physiology, pathophysiology and microbiology, but learn about diseases as well, especially in the years preceding the clerkships. However, the 'distance' between basic biomedical concepts and models at one hand and disease manifestations at the other is considerable and, especially in the early years, the level of integration of both kinds of knowledge may be small. Students in their preclinical years would predominantly draw upon the biomedical knowledge base while solving a case, whereas physicians would use clinical knowledge while thinking about a patient' problem. However, with an increasing accumulation of knowledge in both knowledge bases, chances are, that these distinct bases begin to share an accumulating number of concepts. Therefore, although both types of knowledge remain distinct in memory, this learning process would eventually result in a increasing overlap of concepts, simply because terminological overlap exists in both knowledge bases. Following this line of reasoning, the findings of Experiment 2 would not so much result from knowledge compilation, but rather from mere knowledge accumulation.

In order to make the case for knowledge compilation as opposed to mere knowledge accumulation, more is needed than just an expanding set of overlapping *concepts*. Let us imagine what happens if two knowledge bases about the same domain both accumulate. One would expect to find not only an increasing number of common concepts, but also an increasing number of *common propositions* (i.e. sets of concepts and their relationships), since these propositions are the carriers of causal knowledge relevant to both the biomedical and the clinical way of looking at the world. However, if the clinical knowledge base would originate from compilation of the biomedical knowledge base, one would expect the former only to have relatively few propositions in common with the latter. The essence of knowledge compilation is that chains of interrelated propositions are reduced to a fewer number of propositions *of a different nature*. It is assumed that, through compilation, a chain of interrelated propositions in an elaborate biomedical knowledge base is abridged, resulting in one proposition consisting of the first concept of the first proposition of the chain and the last concept of the final proposition of the chain, and their relation. In other words: Compilation of interrelated sets of propositions results in 'shortcuts'. Therefore, if mere accumulation of both knowledge bases would explain the findings, one would expect the on-line and post-hoc protocols to share not only an increasing number of concepts, but also an increasing number of propositions. If, on the other hand, the findings are the result of compilation, the expectation would be that the number of shortcuts would increase with expertise, whereas the number of identical propositions would be unrelated to level of expertise.

In order to investigate these two alternative interpretations, the biomedical propositions in the pathophysiological networks derived from the post-hoc explanations were matched against the propositions derived from the think-aloud protocols. Next, it was determined whether the think-aloud proposition was identical to the explanation proposition it was matched to. These propositions were labeled 'identical propositions'. A think-aloud proposition was labeled a 'shortcut' if this proposition consisted of two concepts which were part of a chain of two or more propositions in a pathophysiological network. This kind of propositions was considered to represent shortcuts in the search paths through the pathophysiological networks. Two examples of this type of propositions can be found in Figure 5. Figure 5 consists of a part of the pathophysiological network of Expert #A-14, based on his post-hoc explanation of the case. In his think-aloud protocol, two propositions could be found relevant to this part of his network: "Alcohol can cause pancreatitis" and: "Pancreatitis causes a raised level of serum amylase". Mapping the think-aloud proposition "Alcohol can cause pancreatitis" onto his network abbreviates the path to 'pancreatitis' by skipping the concepts 'chemical irritation of the pancreas', 'inflammation reaction', and 'acute pancreatitis (or) chronic relapsing pancreatitis'. Similarly, the think-aloud proposition "Pancreatitis causes a raised level of serum amylase" abbreviates the path from pancreatitis to 'raised serum amylase', omitting the concept 'tissue destruction'. These two propositions, thus, are considered shortcuts, resulting from knowledge compilation.

A propositions was labeled 'other' if in a think-aloud proposition two network concepts are linked in another way. For instance, this would be the case if the expert would have linked 'destruction of tissue' and 'pain'.

------------------- **Insert Figure 5 about here** -------------------

In summary, if an increasing level of expertise is associated with compilation of biomedical knowledge into clinical knowledge, then an increase must be expected in the number of think-aloud propositions that can be characterized as shortcuts of two or more propositions in the pathophysiological networks. If, on the other hand, the increasing proportion of common concepts as illustrated in Figure 4 results from the accumulation of biomedical and clinical knowledge then the number of identical propositions will be expected to increase. Table 7 contains the results of this analysis.

-------------------- **Insert Table 7 about here** --------------------

Analysis of the number of identical propositions in the think-aloud protocols and the pathophysiological networks shows no differential effects of the different levels of expertise ($F(3,15)= 1.63$, $p> .20$). The same observation holds for the number of "other" propositions ($F(3,15)= 1.71$, $p> .20$). By contrast, the number of shortcuts turned out to be significantly related to level of expertise ($F(3,15)= 9.01$, $p< .001$). There is a significant linear component in this effect ($F(1,15)= 21.81$, $p< .001$, without significant deviations, $p> .05$). Figure 6 represents the data graphically.

-------------------- **Insert Figure 6 about here** --------------------

The data clearly indicate that only the number of shortcuts increases with level of expertise, supporting the hypothesis that the results of Experiment 2 are not so much the consequence of mere accumulation of two distinct knowledge bases but the outcome of a compilation process of biomedical knowledge. Only medical experts seem to apply biomedical propositions in their think-aloud protocols which are shortcuts in their biomedical knowledge. In the less experienced subjects this is hardly ever the case.

CONCLUSION

The two experiments presented here replicate the findings earlier reported by Patel and colleagues (Patel and Groen, 1986a, 1986b; Patel, Arocha and Groen, 1986; Patel, Evans and Chawla, 1986; Joseph and Patel, 1987; Kaufman and Patel, 1988). They provide a substantial basis for the conclusion that medical experts, contrary to intermediates and novices, do not overtly apply biomedical knowledge in clinical reasoning. In addition, our results expand the conclusions reached by the Montreal group in that we were able to show that expert biomedical knowledge is compiled and integrated into clinical knowledge. This latter finding contradicts the convictions of Patel, Evans and Groen (1989) that biomedical and clinical knowledge essentially "represent two different worlds" and that, at least in routine cases, biomedical knowledge is not used at all. On the contrary, our findings suggest a tacit role of biomedical knowledge in expert clinical reasoning.

In stage models of expertise development in medicine (e.g. Schmidt and Norman, 1990), it is assumed that a gradual transition from one stage to the next occurs. These authors conjecture that an elaborate network of biomedical knowledge will be built up first. Application of this biomedical knowledge base to clinical cases would result in a transition to compiled, clinical knowledge. The data presented in this article both confirm and complicate this view. Confirmation stems from the finding that medical experts indeed apply clinically relevant, compiled biomedical knowledge. Through this compilation process biomedical knowledge is integrated in clinical knowledge. Complication stems from the finding that our fifth-year students already applied clinical knowledge as well. This clinical knowledge however, cannot be considered compiled biomedical knowledge. Clinical and biomedical knowledge in fifth-year students seem part of clearly distinct knowledge bases that co-exist in their minds. This suggests that biomedical and clinical knowledge both must reach a kind of critical mass first, before they can be successfully applied in clinical reasoning, resulting in the compilation of biomedical knowledge and its integration into clinical knowledge. Therefore, a three stage model is suggested here. In the first (preclinical) stage, biomedical and clinical knowledge develop separately with an emphasis on biomedical knowledge. In the second stage, taking place in the clerkship period during which students are for the first time exposed to real-life clinical cases, emphasis is shifted towards the acquisition of clinical knowledge. The final stage is reached when both knowledge bases have matured to a sufficient extent, and compilation of biomedical knowledge and integration into clinical knowledge occurs.

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TABLE 1.

Overview of Experiments (Design and Outcomes)

researchers	subjects	cases	method	results
Patel & Groen, (1986a)	N=24 8 beginning, 8 second year and 8 final year students	1 Case of acute bacterial endocarditis	Post-hoc; biomedical science text read before diagnosing the case	Diagnostic performance increased with increasing level of expertise
Patel & Groen (1986b)	N=7 expert cardiologists	1 Case of acute bacterial endocarditis	Post-hoc	Pathophysiological explanations provided by experts were less extensive and more coherent as compared with the students' explanations in Patel & Groen (1986a)
Patel, Evans & Chawla (1986)	N=24 8 beginning, 8 second year and 8 final year students	1 Case of acute bacterial endocarditis	Post-hoc; biomedical science text read after diagnosing the case	Diagnostic performance increased with increasing level of expertise; expert pathophysiological explanations of the case were more coherent but contained less biomedical concepts
Patel, Arocha & Groen (1986)	N=4 experts 2 cardiologists and 2 endocrinologists (clinicians and researchers)	2 Cases: - pericardial effusion - Hashimoto's disease	Post-hoc	Explanations provided by practitioners contained less biomedical concepts as compared with researchers, especially in their own domain of expertise
Joseph & Patel (1987)	N= 9 experts 5 cardiologists and 4 endocrinologists	1 Case of Hashimoto's disease	On-line	High-domain knowledge subjects' problem representations were more coherent than low-domain knowledge subjects', whereas less biomedical concepts were activated
Kaufman & Patel (1988)	N=15 5 final year students, 5 residents and 5 endocrinologists	1 Case of Grave's thyrotoxicosis	Post-hoc	Diagnostic accuracy increased with an increasing level of expertise; intermediates' explanations contained more biomedical concepts, while knowledge applied by novices contained more errors and inconsistencies

TABLE 1 continued

researchers	subjects	cases	method	results
Schmidt, Boshuizen & Hobus (1988)	N=40 8 beginning, 8 2nd year, 8 4th year, 8 6th year students and 8 internists	1 Case of acute bacterial endocarditis	Post-hoc	Inverted U-formed relation between level of expertise and amount of biomedical knowledge applied
Lemieux & Bordage (1986)	N=10 4 poor and 5 outstanding students and 1 expert neurologist	1 Case of cervical arthrosis	On-line	Outstanding students applied more detailed biomedical knowledge than the expert; poor students' knowledge is either missing or represented as an unstructured list of facts
Lesgold, Rubinson, Feltovich, Glaser, Klopfer & Wang (1988) (2 studies, also partly reported in Lesgold (1984))	a) N=23 11 junior, 5 senior residents and 5 expert radiologists b) N=12 4 junior, 4 senior residents and 4 expert radiologists	a) 3 Cases analyzed and reported (out of 10): - lobectomy - atalectasis - multiple tumors b) Same 3 cases analyzed and reported (out of 5)	a) On-line (think aloud) b) On-line (think aloud & drawing)	a) and b) Biomedical knowledge applied by experts seems to be more precise and detailed and better suiting in the context of the presented cases, whereas novices' and intermediates' knowledge seemed to lead to many misperceptions
Feltovich, Johnson, Moller & Swanson (1984) (1 experiment, plus a deeper analysis)	N=12 4 students, 4 residents and 4 expert pediatric cardiologists	4 Cases: - subvalvular aortic stenosis - total anomalous pulmonary venous connection - patent ductus arteriosus - pulmonary atresia	On-line	Students' knowledge structure resembles the text book structure; in the experts' knowledge organization extra links, based on pathophysiological similarities, are added furthermore, novices seem to 'reason through' biomedical knowledge in clinical reasoning

TABLE 2

Symptoms and Pathophysiological Process in Pancreatitis

Major causal factors: cholelithiasis or alcohol abuse.
Pathophysiological process: Inflammation of the pancreas. The pancreas is an organ lying deep in the upper part of the abdomen, behind the peritoneum. Its function is to produce enzymes (e.g. lipase, amylase) that play an important role in the digestion of fat and protein. By their very nature, these enzymes are capable of destroying the pancreatic tissue as well. However, since they are released as inactive pro-enzymes, no harm is done. Furthermore, the pancreas produces insulin. Inflammation of the pancreas causes a swelling of the tissue, which may obstruct the pancreatic ducts. By this inflammation pancreatic pro-enzymes are activated in the gland itself, causing destruction of tissue. Pancreatic enzymes are released by this process, directly into the blood stream instead of the alimentary canal.
Symptoms: Pain in the upper part of the abdomen is often very severe, while, because of the location of the organ, physical examination may reveal only minor abdominal findings. Sometimes, pancreatitis is associated with malabsorption, caused by a lack of pancreatic enzymes in the alimentary canal. Since amylase is directly released into the blood stream, laboratory findings often show a high level of serum amylase.

TABLE 3.

Responses of the four Subjects to the Complaint Information (Item 8)

8. complaint: continuous pain in the upper part of the abdomen, radiating to the back	**Novice**	.. (err, so the upper abdomen) that brings us back again to err to, to the pancreas !! . er (radiating to the back) . I can't do very much with that information right now !!
	I-1	... may have to do with the gall bladder . !! may have to do with the pancreas .... !!
	I-2	(he was 38 years old), I belief; yes !! . (a continuous pain in the upper abdomen which radiates to the back); *to what part of the back? the upper part of the back or . directly opposite the upper abdomen?* !!
	Expert	Well, when I am (visiting) someone who is (suffering an acute .. continuous - *since when?* - pain in his upper abdomen, radiating to the back), (who had pancreatitis a year before) .. of whom I don't know for sure if he still drinks alcohol or not after that (course of Resufal), but of whom I do know that he still (has mental problems, so still receives a disability benefit), !! then I think that the first thing to cross my mind will be: well what about that pancreas, !! . how is his liver !! . and also that - considering (his age) - er it is not very likely that there will be other things wrong in his abdomen . er . of a malign thi er nature !! . of course er if he's taking huge amounts of alcohol there is always the additional possibility of a stomach er problem, a stomach perforation !! .. excessive drinking can also cause er serious cardiomyopathy, which er may cause heart defects !!. mmmm, I can't judge the word 'continuous' very well yet in this context !!

TABLE 4.

Responses of the four Subjects on Information about an Attempted Suicide (Item 20)

20. (history) depressions: has been feeling low in the last 1 1/2 week 2 days ago he tried to put an end to everything with 6 Mogadon and large amounts of alcohol	**Novice**	well I daresay he has been drinking a lot again .. ((laughing)) ‖ and err well . er one of the characteristics of depressive patients is that they tend to suicide or actually attempt try to commit suicide ‖ .. and about (those 6 tablets of Mogadon), *I wonder did he appeal to er did anyone call on er the help of a doctor at that moment or did they pump his stomach* ‖ *and what kind of medicine exactly is Mogadon* ‖ *. is it a anti-depressant or something like that* ‖ .. errm . and so here too . er excessive drinking again ..‖
	I-1	.. well . (low for 1 1/2 weeks). indicates only that he did a foolish thing 2 days ago ‖ . for he had given his liver a blow by doing so: (quantities of liquor, 6 tablets of Mogadon) ‖ . that might er . do considerably more serious damage to er the liver than has been the case with that er alcohol ‖
	I-2	(.. Err .. hospitalized a year ago), (Refusal,) .. that's important too, that's important indeed . ‖ er ... then it's quite possible that this left him with a stomach ache ‖ or gastritis. ‖ *but in that case what did they do about it? was he hospitalized for that too, or did he consult a doctor?* ‖
	Expert	...... (with a great deal of), so on top of his excessive drinking . another huge quantity of alcohol ‖ ..... there is this diverting information that yes that (2 days ago he tried to put an end to everything by taking 6 tablets of Mogadon) ... *what happened then?* ‖ Obviously very little ‖ *. why only 6 tablets?* ‖ A serious attempt would demand more than 6 tablets; ‖ *who gave him this Mogadon?* ‖ . errm .. it's important information because it indicates that we have to deal with a person who is in an emergency ‖.. and you can't .. ignore this track, but you will have .. at least I would first . (that this acute stomach ache)(with these colic-like attacks) er which started in the morning), (attended er now by vomiting once)(er with a great deal of alcohol), would first like to find out and ascertain if that needs further exploration, before I proceed on this track; ‖ but it's a very clear signal ‖ *.. what was his wife's reaction?* ‖ nothing mentioned err ‖ .. now where is he trying to get at this time of the day, ‖ by asking his doctor for a house call at 9 p.m.. at an hour at which you can expect that if someone is coming . that a doctor will have a bit more time for a talk. ‖ (abbreviated.)

TABLE 5.

Summary Table of Descriptors of the four Subjects' Think-aloud Protocols

	Novice	**Intermediate-1**	**Intermediate-2**	**Expert**
number of basic mental operations	160	120	135	256
number of knowledge application propositions	75	71	39	78
number of biomedical propositions	42	24	7	5

TABLE 6.

Summary Table of Descriptors of the Think-aloud Protocols of Subjects of four different Levels of Expertise (Means and Standard Deviations)

	Novices	**Intermediates-1**	**Intermediates-2**	**Experts**
N	6	4	4	5
number of propositions	38.8 *(15.4)*	46.0 *(4.69)*	25.0 *(8.042)*	35.8 *(11.56)*
number of biomedical propositions	11.0 *(8.60)*	21.8 *(12.55)*	5.0 *(4.83)*	5.2 *(2.49)*
proportion of biomedical propositions	.24 *(.18)*	.47 *(.26)*	.17 *(.13)*	.14 *(.06)*

TABLE 7.

Average Number of Identical and 'Other' propositions and Shortcuts Representing the Similarity between Think-aloud Protocols and Post-hoc Explanations in four Groups with different Levels of Expertise (Means and Standard Deviations).

	Novices	**Intermediates-1**	**Intermediates-2**	**Experts**
identical propositions	1 *(.894)*	2.25 *(2.63)*	2.25 *(1.5)*	3.4 *(2.074)*
'other' propositions	.33 *(.516)*	0 *(0)*	0 *(0)*	0 *(0)*
shortcuts	.17 *(.408)*	.25 *(.5)*	0 *(0)*	2.8 *(1.789)*

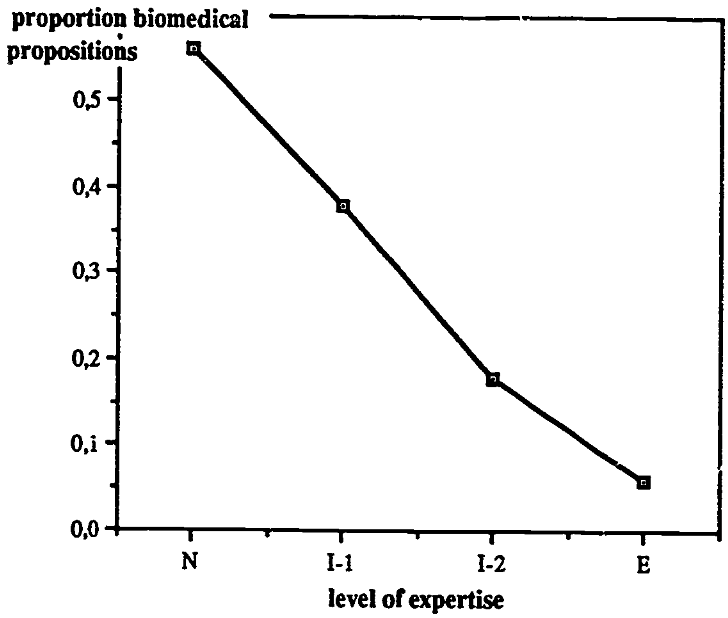

Figure 1. Relation between level of expertise and proportion of propositions extracted from the think-aloud protocols that were classified as biomedical propositions.

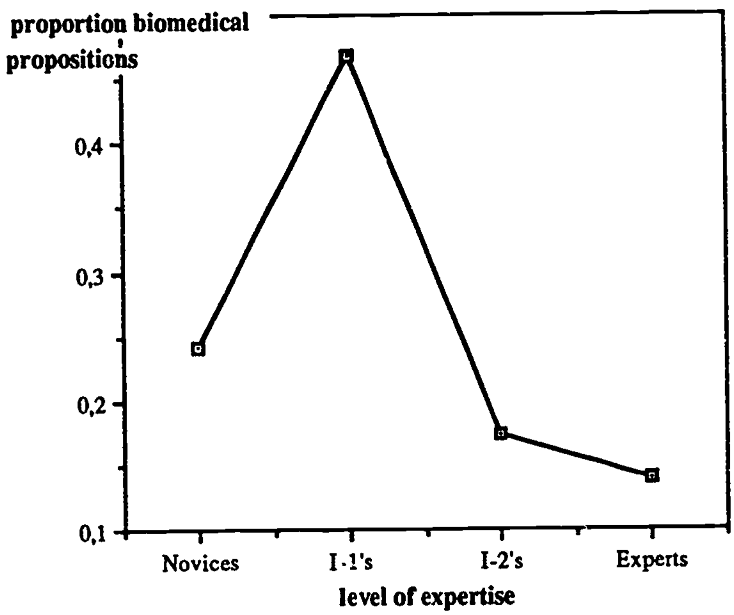

Figure 2. Proportion biomedical knowledge applied by subjects of varying levels of experience in diagnosing a clinical case while thinking aloud in Experiment 2.

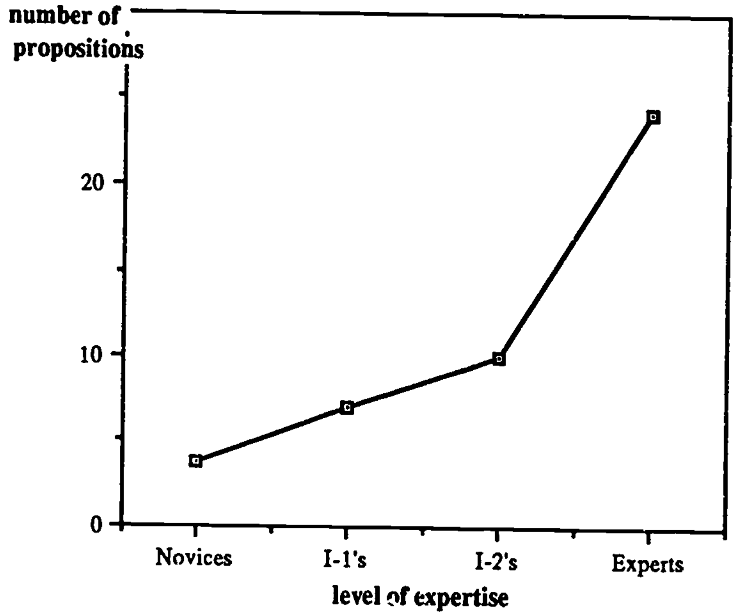

Figure 3. Number of propositions applied by subjects of different levels of expertise in explaining the pathophysiological process that caused a patient's complaints.

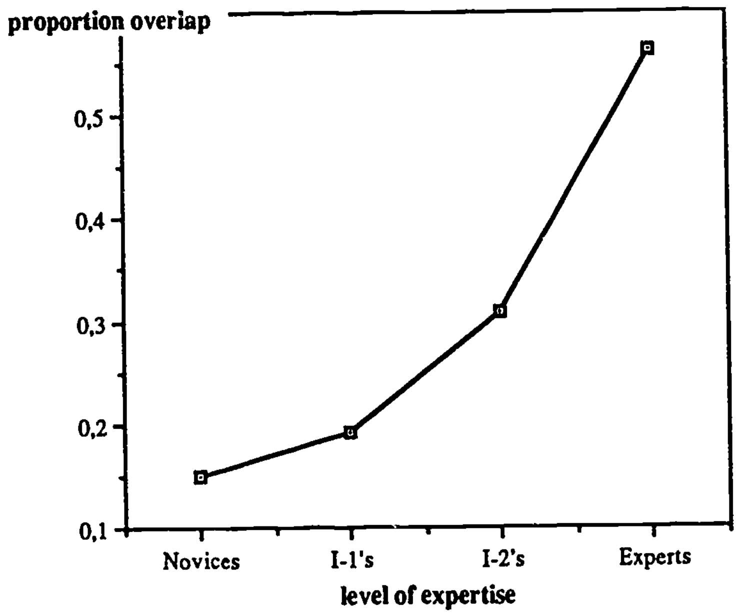

Figure 4. Number of propositions applied by subjects of different levels of expertise in explaining the pathophysiological process that caused a patient's complaints. Overlap (proportion of common concepts) between the propositions derived from the think aloud protocols and the pathophysiological explanations.

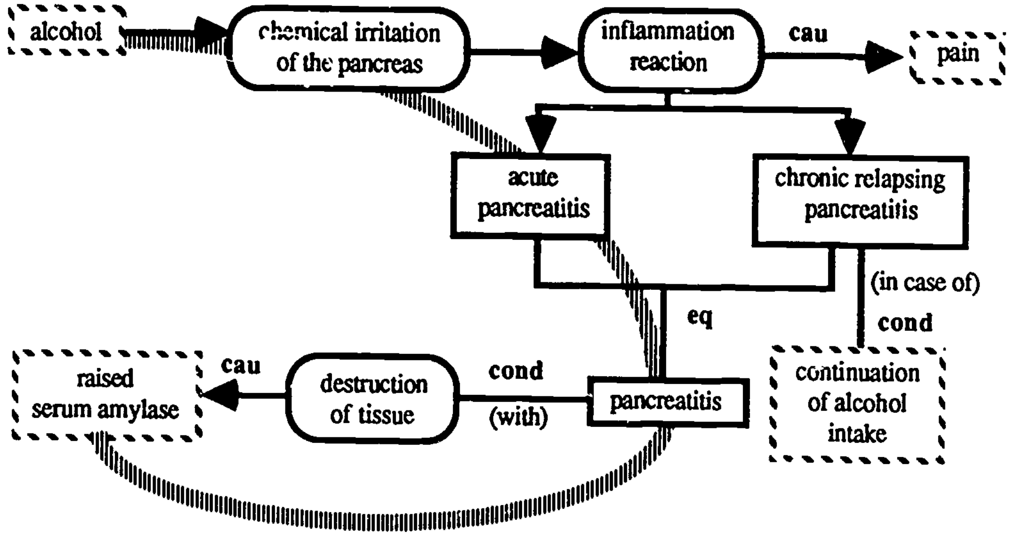

Figure 5. Part of the pathophysiological network of Expert #A-14, with the shortcuts emerging from matching the think-aloud propositions onto the network propositions.

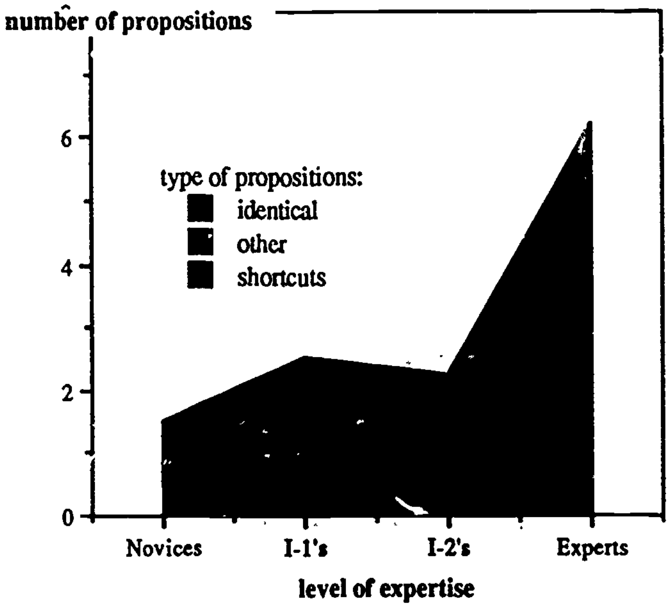

Figure 5. Three types of propositions representing the similarity between on-line and post-hoc propositions with subjects of four different levels of expertise.

APPENDIX

Protocol-framework Intermediate-2

items	knowledge application propositions
1. man, married, 38 years old, 2 children	
2. vocation: gasfitter incapacitated (because of mental problems) since 4 years; does some odd jobs once in a while; also for his former employer	
3. (prior illnesses) recurring neurotic depressions since the age of 24 has been hospitalized in a mental institution for 3 months psychiatric out-patient since discharge	
4. (prior illnesses) increasing alcohol abuse since 6 years	--> mental problems --> or physical complaint
5. (prior illnesses) hospitalized 1 year ago, because of an attack of acute pancreatitis	--> may have to do with (F) alcohol
6. (prior illnesses) Refusal treatment 1 year ago	--> heavy drinker
7. type of consultation: house call, 9.00 p.m.	--> (cond) acute complaint
8. complaint: continuous pain in the upper part of the abdomen, radiating to the back	--> gall bladder --> or pancreas
9. (history) started this morning with a vague pain in the abdomen	
10. (history) pain has increased since onset; constant now	--> (cond neg) biliary colic --> (cond neg) gall stones
11. (history) it is a heavy, boring pain, piercing right through	
12. (history) cannot localize the pain with one finger	--> rather diffuse pain
13. (observation) attitude: the patient sits in a chair, continually bending over or pulling up his legs; otherwise moves normally	--> avoid contraction of abdominal muscles --> (cond) something wrong with peritoneum --> (spec) beginning peritonitis --> (cond) perforated peptic ulcer

14. (history)
has just vomited;
did not affect the pain

<-- (cau) peritoneum involved

15. (history)
the pain is similar to the pain he has been hospitalized with; but then it started very suddenly, and moreover it was worse

--> peritoneal irritation

16. (history)
he has had this sort of radiating to the back more often in the last while, but never as bad as it is now

--> (iden) chronic process manifesting itself from time to time

17. (history)
Most of the time it vanished within a day time

--> (cond neg) stomach rupture
--> (cond) peritoneal irritation
--> (cond) biliary
--> or (cond) pancreatic region

18. (history)
he has tried some Aspirins; that didn't have any effect

--> Refusal has had no effect

19. (history)
alcohol abuse: drinks again since half a year
drinks the same amount as he used to

--> [enough -->(cau) liver]
--> [liver pathology and possibly attending biliary disease]

20. (history)
depressions: has been feeling low in the last 1 1/2 week
2 days ago he tried to put an end to everything with 6 Mogadon and quite a lot of alcohol

--> (cau) considerably more serious damage to the liver

21. (observation)
appearance: doesn't look ill, but has face is distorted with pain

22. (observation)
appearance: not anaemic, not jaundiced

--> (cond neg) [liver damage --> (cau) jaundice]
--> (cond neg) [chronic liver damage --> (cau) something wrong with blood]

23. (history)
according to other people he has been jaundiced once in a while during the last time

--> (cond) biliary disease
--> (cau) disorders in the biliary tract
--> (cau) liver

24. (history)
appetite: poor

--> (cond) liver

25. (history)
eating habits: irregular

26. (history)
eating habits: often eats chips and a salad, a sausage or a meat ball

--> fatty
--> (cond) bile

27. (history)
today's menu: he has had breakfast with ham and eggs and bread
dinner yesterday: spaghetti with tomato sauce

28. (history)
pain has no relations with meals

29. (history)
weight: has lost ± 5 kg in the last 6 months

--> (cond) [biliary disease
--> (cau) non-digestion of fats]

30. (history)
defecation: no problems, defecation pattern not changed

--> (cond) biliary disease

31. (history)
defecation: paler and more stinking stools according to the patient

--> (cond) biliary disease
[(F) no problems with defecation
--> (cond neg) obstipation]
<--> ??????? biliary tract obstruction

32. (history)
defecation: last bowel motion was yesterday

33. (history)
temperature: 37.8°C at 6 p.m.

--> no temperature

34. (physical examination)
pulse rate: regular, 72/min.

& (F) T: 37.8°C
--> (cond neg) inflammation
--> (cond neg) cholecystitis
& (H) biliary tract obstruction
<-- (cau) stone
<- - [of (cau) tumor
<-- (cond) lost 5 kg]

35. (physical examination)
BP: 140/95

--> borderline

36. (physical examination)
respiration rate: 18/min.

37 (physical examination)
abdomen, inspection: moderately distended, moderately moving with respiration

38. (physical examination)
abdomen, auscult.: diminished bowel sounds

--> peritoneal irritation
--> (cau) automatically decreases bowel motility

39. (physical examination)
abdomen, perc.: liver and spleen not enlarged

--> or (cond) liver not yet seriously damaged
--> or (cond) liver seriously damaged
& (F) other findings
--> (cond) liver not yet very seriously damaged

40. (physical examination)
abdomen, palp.: epigastric tenderness; no defence; no further tenderness in the abdomen; no further palpable anomalies in the abdomen

--> (cond neg) peritonitis

41. (physical examination)
cor: perc. not enlarged; normal sound; regular rate; no murmurs

--> no cardial defects

42. (physical examination)
pulm.: both boundaries normally moving; normal respiration sounds

& (H) if peritoneal irritation
 --> only minor irritation

43. (physical examination)
aa. femorales, palp.: good pulsations at both sides
ausc.: no abnormal murmurs

--> (cond neg) something atherosclerotic there

44. (physical examination)
rectal examination: no anomalies

45. (physical examination)
venous pressure not raised

[increased venous pressure
 <-- (cond) liver actually congested
  <-- (cau) heart suffering
   <-- (cond neg) (F) indications
    --> heart functions properly & liver not seriously damaged or diminished liver function

46. (physical examination)
parotic glands: not enlarged

--> (cond neg) inflammation there

47. (history)
no further complaints

48. lab findings:

serum amylase: 128 U
(normal 8-16)

--> seriously increased

glucose: 6.0 mmol/l
(normal 4.4-5.8)

--> slightly increased
 --> probably within range of measurement

WBC: 11.0x109/l
(normal 5-10x109)

--> slightly increased

ESR: 15 mm after 1 hour
(normal -10)

--> increased

Hg: 7.8 mmol/l
(normal 8.8-11.2)

--> normal

(F) serum amylase
--> (cond) liver not functioning as well as it should
--> or (cond) pancreas

(F) glucose slightly increased
& (H) if no measurement error
--> pancreas
 --> (spec) pancreas tail, not pancreas head

(F) BSE increased
--> (cond) inflammation
--> or (cond) tumor

[[(H) biliary tract obstruction not actually attended by inflammation
--> (cau) minor liver congestion
--> (cau) slightly malfunctioning liver

& [(F) lab findings
--> (cond) decreased functioning of the pancreas]]

& (F) 5kg weight loss in 1/2 jr
--> (cond) cancer of the pancreas head spreading to the tail
--> (cau) obstructing the biliary tract