ON THE APPLICATION OF MEDICAL BASIC-SCIENCE KNOWLEDGE IN CLINICAL REASONING: IMPLICATIONS FOR STRUCTURAL KNOWLEDGE DIFFERENCES BETWEEN EXPERTS AND NOVICES [1]

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Knowledge structures in memory and knowledge application are concepts which are closely related in theories on expertise in semantically rich domains. Glaser (1986) takes an extreme position by hypothesizing that novices' failure to solve a problem can be attributed solely to structural aspects of their knowledge which prohibit activation. This claim is supported by research findings of Allwood & Montgomery (1981), who showed that novices, while solving problems, have difficulties in activating relevant knowledge, and even seem unaware of their possessing that knowledge. In order to become applicable in problem-solving situations, knowledge must be conditionalized.

Lesgold (1984), applying Anderson's (1982) theory on learning of cognitive skills to medicine proposed that medical basic-science knowledge, initially declarative in nature, becomes tied to the conditions under which it can be applied, is compiled and tuned to medical practice.
Feltovich and Barrows' (1984) model of medical expert knowledge can be perceived as the final stage in this developmental process. They propose a multi-layer model in which medical basic-science knowledge becomes integrated into what they call "illness scripts". In their view, a physician who is confronted with a patient attempts to generate a description of the patient's major malfunctions (the Fault), the signs and symptoms which (s)he suffers from (the Consequences of the Fault) and how the patient's condition came to be (the Conditions that Enabled the Fault). For instance, sex, age and weight are conditions in the patient, associated with several kinds of diseases. Increasing age is associated with a higher incidence of cancer, whereas cardiovascular diseases are more commonly found in males and in people suffering from obesity. Being overweight, over 45 years of age and a female are associated with bile stones. Enabling conditions as defined by Feltovich & Barrows (1984), impose constraints on the set of plausible hypotheses about the Fault causing the patient's signs and symptoms. That is why bile stones will more easily be expected in a 55 year old lady who is 15 kg overweight, than in a thin young man, although both may present suffering from an attack of abdominal pain. The knowledge applied in identifying Enabling Conditions, Faults and Consequences, may be part of several medical subdomains and specialties like epidemiology, microbiology and internal medicine. Feltovich and Barrows claim that in such an illness script, basic-science knowledge plays a important and integrating role. Its causal nature determines how variations in patient findings can be accounted for.

Evidence for this proposition is provided by Lesgold, Feltovich, Glaser & Wang (1981) in the domain of radiology. They found that knowledge becomes more and more accurate in the course of development toward expertise, and that knowledge applied by experts in characterizing chest X-rays was far more extensive, detailed, relevant and goal-oriented as compared with intermediates' and novices' knowledge. Other authors, however, notably Boshuizen, Schmidt & Coughlin

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(1987) and Patel, Evans & Groen (1988), suggest that basic-science knowledge plays a less dominating role in expert performance in medicine, while it does play a role in the earlier, intermediate stages. Their suggestion is based on the relative absence of references to basic science concepts in explanations provided by experts when asked to describe the pathophysiological processes underlying signs and symptoms displayed in a clinical case. Thus, two conflicting hypotheses about the role of basic-science knowledge in expert performance can be identified in the literature.

In this paper, research on the role of basic-science knowledge in clinical reasoning will be reported. The question of interest is whether or not basic-science knowledge plays an increasing role in the development of expertise. In addition an attempt will be made to determine at which stage in the development towards expertise illness scripts emerge as organizers of patient information. In order to investigate these issues two experiments were carried out. In Experiment 1 an explorative, qualitative approach was taken, utilizing four subjects with different degrees of expertise. These subjects were asked to think aloud while processing sequentially presented patient information. In Experiment 2, results of Experiment 1 were verified in a sample of 24 subjects, using both qualitative and quantitative procedures.

EXPERIMENT 1

Experimental Method

Subjects

Four subjects at different levels of medical expertise participated in this study: one novice (a second year medical student); two intermediates ("I-1", a fourth year student nearly finished preclinical training; and "I-2", a fifth year student who had finished both primary care and internal medicine clerkships) and one expert (a family physician with four years of experience).

Procedure

The subjects were presented with a case of chronic relapsing alcohol-induced pancreatitis with minor pancreatic insufficiency. The case describes a 38 year old, unemployed male with a history of neurotic depressions and alcohol abuse. One year earlier, he 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.

The case was presented on 48 typed cards, each containing one or more items of information characterizing the patient, the present history, physical findings or lab findings.

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. Sessions were recorded on tape and verbatim transcripts were produced.

Analyses

The Feltovich & Barrows model was used as an analytic tool. First, the original case, as presented to the subjects, was analyzed using the Feltovich and Barrows categories. For each case item, it was decided whether or not it fit with the pancreatitis script. Next, each script item was assigned to one of the model's categories. Subsequently, the four think-aloud protocols were analyzed counting the number of links in reasoning chains in which case items were clustered together, and the number of rules connecting concepts in a chain. A link in a chain is defined here as the association between two case items constructed by the subject. These links were classified utilizing the Feltovich and Barrows model.

For instance, when the expert is confronted with the first Consequence item (#8):

Complaint : "continuous pain in the upper part of the abdomen, radiating to the back"

He responds:

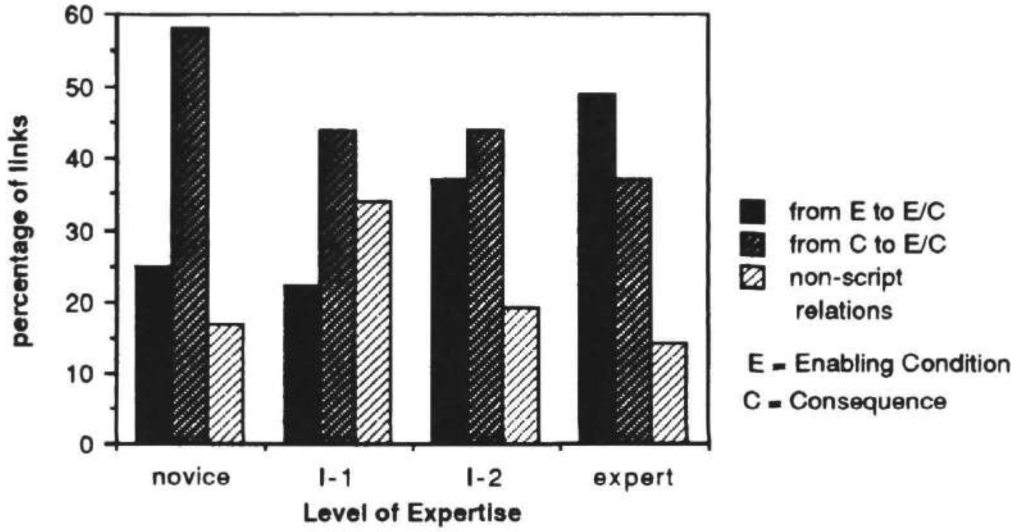

figure 1. Percentage of links between case items

"Well, when I visit a person (7) with an acute, continuous pain in his abdomen, radiating to the back (8), who suffered from pancreatitis a year before (5), where I don't know for sure whether or not he is still drinking after the Refusal cure (6), but I do know that his mental problem still exists (2), well I think that I'll think first: how is his pancreas? how is his liver? and that -because of his age (1)- other malignant processes in the abdomen are less probable." (relevant item# are between brackets.)

Here, the expert is linking an Enabling Condition (#7), Consequence (#8) and four other Enabling Conditions (#1,2,5&6) into a chain. Thus five links emerge from this excerpt: E #7 - C #8, C #8 - E #1, E #1 - E #2, E #2 - E #5 and E #5 - E #6. These links are classified as E-to-C, C-to-E and 3 E-to-E links.

In order to investigate the type of knowledge subjects were using in chaining the case items, rules were abstracted from the protocols. Rules were indicated in the protocols by expressions like: "<...> indicates <...>", "<...> makes me think of <...>", or "if you think of <...>, you always have to think of <...> as well". The abstracted rules were represented as IF-THEN statements. In the example above, that was derived from the expert's protocol, two complex rules can be identified:

IF	(house call & acute, continuous pain in upper abdomen & pancreatitis yr before & may drink alcohol & mental problems)	THEN	(pancreas or liver)
IF	(house call & acute, continuous pain in upper abdomen & pancreatitis yr before & may drink alcohol & mental problems & his age (38))	THEN	(less probable) (malignancy in abdomen)

Results and Discussion

Figure 1 summarizes the results of the analysis of the nature of the chains between case items found in each of the four protocols (E-to-E and C-to-E chains were take together as were C-to E and C-to-C chains.) The data show that non-script chains decrease from the intermediate to the expert levels, suggesting an increasing skill in deciding which patient findings are important in the final diagnosis. Furthermore, they show that reasoning chains, starting from a Consequence (a sign or a symptom) decrease with increasing expertise, whereas reasoning from Enabling Conditions to other Enabling Conditions or to Consequences (denoted E/C in figure 1) increases with experience. These data suggest an increasing use of this kind of knowledge in clinical reasoning.

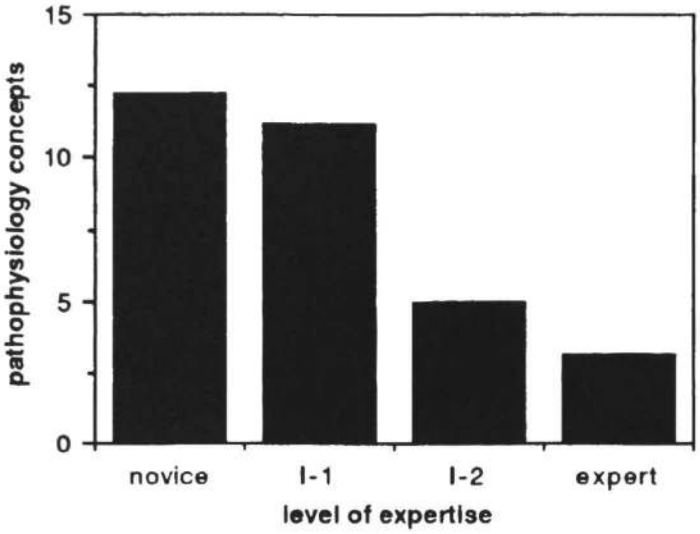

figure 2. Percentage of basic science concepts identified in the rules

In all subjects, in most rules that are abstracted from the protocols, case items are linked to a hypothesis about the patient's Fault. All subjects used Consequences to generate an underlying Fault, but the expert and subject I-2 in addition, displayed rules concerning relations between Enabling Conditions and a possible Fault. Again, indicating an increasing use of this kind of knowledge.

In summary, these results suggest that all subjects apply illness-script knowledge to interpret the nature of a patient's disease as is suggested by Feltovich and Barrows' model of medical expertise. With the development of expertise a shift can be observed from reasoning from Consequences to reasoning from Enabling Conditions in order to make sense out of a problem. It is particularly interesting to note that novices already apply illness-script knowledge before all relevant basic-science knowledge is acquired.

Figure 2 contains percentages of basic science concepts extracted from the rules applied by the four subjects. The data suggest that the application of basic-science knowledge is primarily characteristic of lower levels of expertise (the novice and subject I-1). In the expert protocol, hardly any references to basic science are made, indicating that basic-science knowledge does not play an overt role in expert clinical reasoning. A straightforward interpretation of this finding might be that the application of basic-science knowledge is characteristic of novice problem solving. The data suggest that the nature of the knowledge used by the expert in diagnosing a case is essentially illness-script related knowledge, whereas his basic-science knowledge has become inert (Bransford, Sherwood, Vye & Rieser, 1986) or even rudimentary.

However, an alternative interpretation is possible. Lesgold's (1984) theory suggests expert basic-science knowledge to be compiled and integrated. And since Ericsson & Simon (1984) assume that the application of compiled knowledge leaves no traces in think-aloud protocols, it may be possible that in experts basic-science knowledge plays its central and integrating role in a tacit way. This assumption however, would be at variance with data provided by both Lesgold, Feltovich, Glaser & Wang (1981) using the same thinking-aloud methodology, which suggests an explicit use of basic-science knowledge in clinical problem-solving.

In order to further investigate these alternative hypotheses on the role of basic-science knowledge in clinical reasoning, a second experiment was carried out. The knowledge actually applied in clinical reasoning was investigated utilizing the same on-line methodology as in Experiment 1. In addition however, the basic-science knowledge applicable to the case was elicited afterwards through a direct probe technique (Patel & Groen, 1986). It was expected that matching

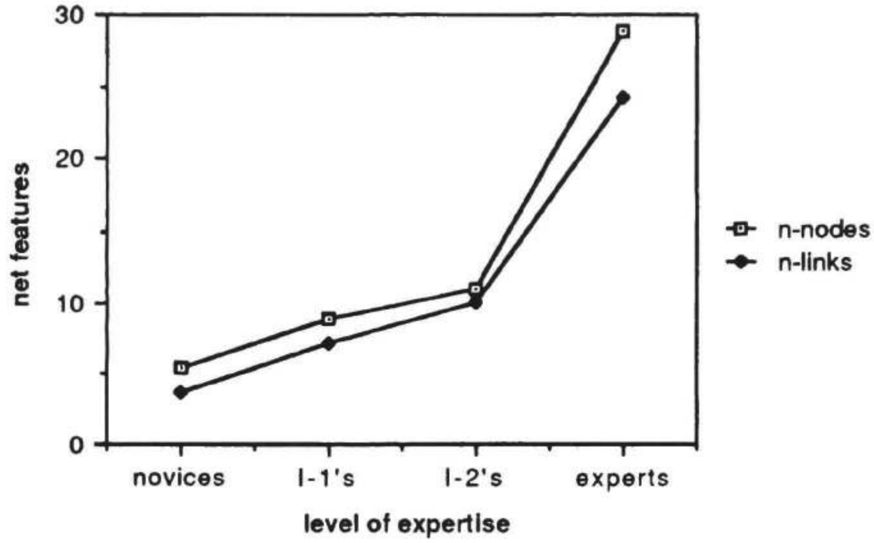

Figure 3. Average values of features of the semantic nets derived from the pathophysiological explanations of the case

information from these two sources would provide evidence as to whether expert basic-science knowledge is essentially rudimentary or inert, or whether it is compiled and integrated into illness-script knowledge.

EXPERIMENT 2

Experimental Method

Subjects

In Experiment 2, 20 subjects (6 novices, 4 fourth year and 5 fifth students, and 5 experts) participated. They were of the same levels of expertise as the subjects who participated in Experiment 1.

Procedure

Subjects were presented with the same case of pancreatitis using the same methodology as in Experiment 1. The subjects were asked to think aloud and to provide a differential diagnosis. Subsequently, they were asked to describe the pathophysiological process which, in their view, would explain the case.

Analysis

The think-aloud protocols were analyzed with respect to the type of knowledge that was applied in clinical reasoning. This was done in the same way as in Experiment 1. The pathophysiological protocols were analyzed using a methodology described by Patel & Groen (1986). Essentially, this procedure consists of a propositional analysis of the generated text. The resulting propositions are graphically presented in a semantic network, displaying the concepts and their relations appearing in the propositional analysis. The number of concepts and their connecting links were determined. Subsequently, the semantic networks were matched against the subjects' rule sets derived from the think-aloud protocols. The number of shared concepts was used as a measure for the overlap between semantic networks and rule sets.

Results and Discussion

Three alternative hypotheses emerged from Experiment 1.

1. Expert basic-science knowledge has become rudimentary. If this is the case, the experts'

pathophysiological protocols will be less elaborate than the intermediates', expressed in a smaller number of concepts.
2. Expert basic-science knowledge has become inert. If this is the case, no overlap will be found between expert basic-science and illness-script knowledge.
3. Expert basic-science knowledge has become integrated into illness-script knowledge. If this is the case, an increasing overlap between basic science and illness-script knowledge is expected.
These hypotheses are tested in a two-step approach. First, the extent of basic-science knowledge is investigated in order to test hypothesis 1. In figure 3, the results of this analysis are shown. Both analyzed net features: number of nodes ($F(3,16) = 3.811$, $p = .031$) and number of links ($F(3,16) = 3.567$, $p = .0379$) vary monotonously with increasing expertise. This indicates an ever increasing amount of basic-science knowledge about pancreatitis instead of a knowledge base that has become rudimentary.
As hypothesis 2 and 3 are mutually exclusive, they were jointly tested in the next step. It was found that the overlap between the semantic networks and rule sets increases monotonously from .149 in the novices to .562 in the experts ($F(3,15) = 19.854$, $p < .0001$). This finding demonstrates that in the more experienced and knowledgeable subjects basic-science knowledge is better integrated into the knowledge that is applied in clinical reasoning.
In summary, the results of Experiment 2 show that expert basic-science knowledge is more extensive than intermediate or novice knowledge. The increasing overlap between semantic networks and rule sets indicate that expert basic-science knowledge is neither inert nor rudimentary, but rather is integrated into illness-script knowledge. The results of Experiment 1, demonstrating the absence of this type of knowledge in clinical reasoning may be attributed to its compiled and integrated character.

GENERAL DISCUSSION

The results of Experiment 1 and 2, taken together, show two remarkable trends in the development of medical expert knowledge. The first experiment focussed on the application of illness-script knowledge, and the results suggest a fundamental restructuring of medical knowledge originating from various domains and subject matter. In clinical reasoning, this restructuring is evident in the increasing use of Enabling Conditions in the case description, and in a decreasing dependency on signs and symptoms. In addition, it was found that it was particularly the novice subject and not the expert, who overtly applied basic-science knowledge while reasoning about the case. Since Feltovich & Barrows (1984) assume that basic-science knowledge has an integrating role in expert clinical reasoning, this finding was unexpected. The second experiment showed that the absence of basic science concepts in expert clinical reasoning was not the result of a basic-science knowledge base which had become rudimentary. On the contrary, expert basic-science knowledge is more elaborate, but the concepts in the rules they actually apply in clinical reasoning coincide more often with pathophysiological knowledge suggesting that experts' basic-science knowledge can be run in compiled mode and is integrated into illness-script knowledge.
However, the finding that in the reasoning of all subjects, even the most novice, the application of illness-script knowledge is prominent, does not support Lesgold's theory (1984) of a compilation process starting from basic-science knowledge and resulting in illness-script knowledge. The results of the present experiments suggest that initially both knowledge layers are built up separately, and gradually become integrated during the developmental process toward expertise.

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