BIOMEDICAL KNOWLEDGE AND CLINICAL EXPERTISE

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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. Many organs and other structures in the human body were described since that time, while after the development of the multi-lensed microscope, organ structure and physiology could be studied in more detail. Through these efforts, the secrets that were kept safe in the 'box' were discovered. Important physicians such as Boerhaave (1668-1738) proved the significance of biomedical sciences (e.g. anatomy and physiology) for the clinical sciences. Research into the structure and functioning of the human body provided an increasing insight in its normal functioning and in the way it restores disturbances of its equilibrium. These research efforts resulted in a deeper insight in the mechanisms underlying long known empirical rules of thumb became understood and, as a consequence, medicine developed from 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. Feltovich and Barrows (1984), for instance, hypothesized that biomedical knowledge plays an integrating role in the understanding and diagnosis of a clinical case. Feltovich' and Barrows' position 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 and 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[1]. According to these investigators, the application of biomedical knowledge is in particular characteristic for *non-expert* reasoning. More generally stated: the application of biomedical knowledge is associated with non-automatic problem solving and will be found in the diagnosis of non-routine cases. But, as Boshuizen, Schmidt and Coughlin (1987) already pointed out, there is reason to assume that this debate results from incomplete models of the role and structure of clinical and biomedical knowledge at consecutive stages of the development of medical expertise. Aim of the present paper is to attain more insight in the organization of biomedical and clinical knowledge and to investigate possible mechanisms responsible for changes in the role and organization of clinical and biomedical knowledge in the course of the development from novice to expert.

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[1]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.

In order to attain these goals, an experiment was designed in which the application and availability of clinical and biomedical knowledge in clinical reasoning were investigated. Clinical and biomedical knowledge *application* were measured by analyzing the subjects' think-aloud protocols. The *availability* of biomedical knowledge was assessed from the subjects' post-hoc explanation of the biomedical process underlying the patient's signs and symptoms. Four levels of expertise were incorporated and it was expected that the overt application of biomedical knowledge would decrease with an increasing level of expertise (Boshuizen, Schmidt & Coughlin, 1988). Furthermore, two variations of the same case were used: a typical and an atypical one. According to Schmidt, Boshuizen and Hobus (1988) and to Patel, Evans and Groen (1989) this atypical case, rather than the typical variant would give rise to biomedical reasoning, because physicians can only to a lesser extent rely on automatic processing while diagnosing an atypical case.

The question of knowledge development and the relative roles of biomedical and clinical knowledge will be addressed in a three step approach. The first step is to find an answer to the question 'Does the application of biomedical knowledge in clinical reasoning decrease with an increasing level of expertise?' Should this question be answered with 'yes', as is expected, then the next question is whether this decrease in the application of biomedical knowledge is associated with a decrease in the availability of this kind of knowledge in long term memory The final step aims at a clarification of the underlying developmental mechanism.

Method

In this experiment 38 subjects participated, 28 students and ten physicians. Ten subjects were second year students, eight subjects were fourth year students. Their knowledge structure and knowledge application were assessed at the end of the second semester, hence the second year students may be assumed to have acquired all relevant biomedical knowledge, while the fourth year students will have studied the relevant biomedical and clinical subjects. Furthermore, ten fifth year subjects participated who had finished their clerkships in internal and family medicine. The expert group consisted of ten family physicians with at least four years of experience.

The subjects were presented with a case of pancreatitis. The patient was a 38 year old, unemployed male with a history of neurotic depressions and alcohol abuse. One year earlier, he had been hospitalized with abdominal complaints, and now calls the family physician with a complaint of severe, boring pain in the upper part of the abdomen. This patient suffered from a chronic alcohol-induced pancreatitis. The subjects' task in this experiment 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.

The case was presented in one of two forms, a typical or an atypical case of alcohol induced pancreatitis with several complications. In the typical form, both the patient's medical background and signs and symptoms fitted with what can normally be expected in this class of patients. In the atypical case several misfits occurred, for instance in the description of the pain and in the lab findings. However, according to a panel of four physicians the diagnosis of pancreatitis was still the most plausible, albeit in a more chronic and less vehement form than in the typical case.

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 was applied in order to interpret and diagnose the case. The identification of those 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 those segments containing more than one single 'basic conceptual operation' (e.g. generate a new hypothesis or verify an existing hypothesis, planning further information acquisition or identifying information need) were further subdivided, so each protocol segment may be assumed to represent one basic conceptual operation. Next, all segments pertaining to goal management and information need are excluded from the analysis as are segments pertaining to the perceived quality of the resulting problem representation (e.g. "I am not sure that 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 charted in semantic networks. In these networks, biomedical propositions were discriminated from non-biomedical propositions[2]. Criterion for this discrimination is the *object* of the proposition. Propositions concerning pathological principles, mechanisms or processes underlying the manifestations of a 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 means 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 a 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. 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 37 subjects.

Post-hoc explanations

The explanations of the underlying pathophysiological process were analyzed utilizing a method describe by Patel and Groen (1986). 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.

Results

On-line knowledge application

The number of propositions extracted from the think-aloud protocols did not vary with an increasing level of expertise ($F(3,29)= 1.294$; $p= .2951$). However, the case variant diagnosed by the subjects strongly affected the number of knowledge application

[2] 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.

propositions found in the think-aloud protocols (F(1,29)= 8.821; p= .0059). Figure 1 shows this effect. Apparently, diagnosing the atypical case required more knowledge application than the typical case.

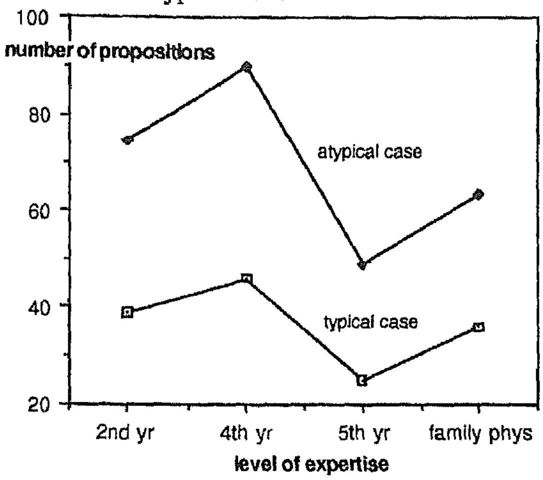

Figure 1. Number of knowledge application propositions extracted from the think-aloud protocols.

These knowledge application propositions were expressed at a varying number of case items. The number of items responded to varied with the subjects' levels of expertise (F(3,29)= 2.856, p= .0542) but did not vary with case type (F(1,29)= .129, p= .7218). Figure 2 shows that the fifth year students responded to the fewest number of items, indicating that these subjects were more selective than the other subjects.

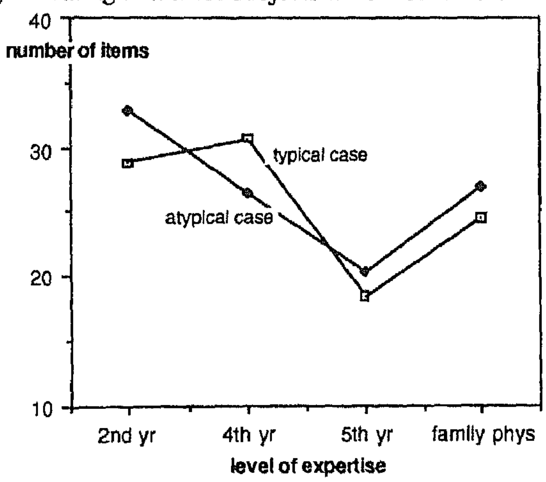

Figure 2. Number of case items responded to with knowledge application propositions

The share of biomedical knowledge in the total number of knowledge application propositions also varied with level of expertise (F(3,29)= 5.196, p= .0054), but not with case type (F(1,29)= .712, p= .4056), nor an interaction of both factors was found (F(3,29)= .263, p= .8515). These effects are represented in Figure 3.

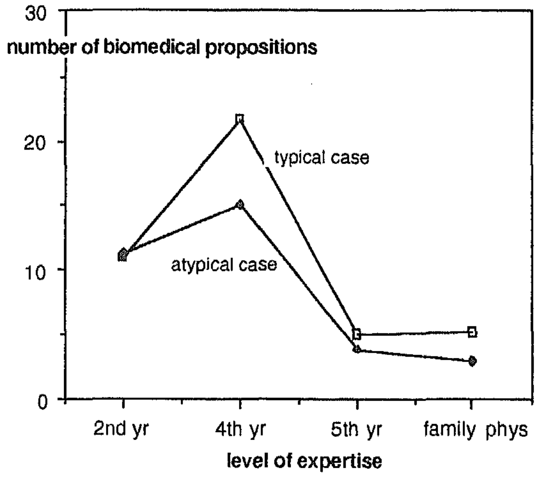

Figure 3. Number of biomedical propositions extracted from the think-aloud protocols.

In summary, subjects of different levels of expertise did not differ in the amount of knowledge applied in clinical reasoning. Notwithstanding that, level of expertise correlated with the number of case findings the subjects responded to with knowledge application propositions. Especially, fifth year students responded to a low number of case items, that is to say to less than half of them. Finally, the number of biomedical propositions also varied with level of expertise. Again this number was very low in the fifth year students, but the experts applied even less biomedical propositions. A peak was found in the fourth year students group. Practical experience seems the key to these differences between 2nd and 4th year students at one hand and 5th year students and experienced physicians at the other hand. So far these findings seem to confirm our hypothesis that the application of biomedical knowledge decreases with an increasing level of expertise, be it after an initial rise between the second and fourth year of study. However, this conclusion is complicated by another remarkable finding, regarding the difference in the number of knowledge application propositions applied while diagnosing the two different cases. Apparently, the atypical case required more cognitive effort. Notwithstanding that, the subjects did not apply more biomedical knowledge as was hypothesized.

Post-hoc knowledge application

The number of propositions in the post-hoc explanations was correlated with the subjects' level of expertise (F(3,30)= 4.168, p= .014). Figure 4 shows an almost monotonic increase with level of expertise. Increasing levels of expertise appear to be associated with a growth in the biomedical knowledge of pancreatitis and not with a decrease of the availability of this kind of knowledge as was hypothesized. Again, no differences related to case type were found (F(1,30)= .701, p= .4092). This finding is in sharp contrast with the finding that the on-line application of biomedical knowledge decreased after the fourth year level.

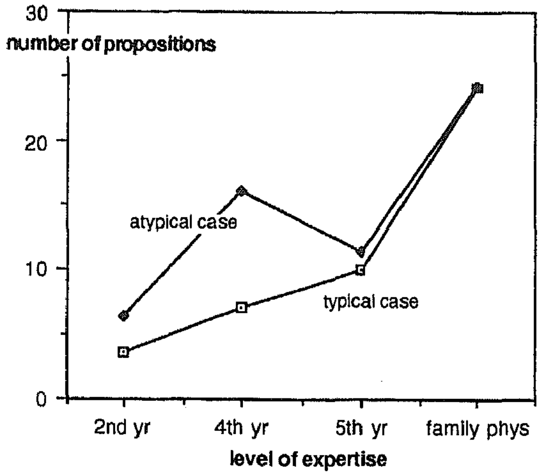

Figure 4. Number of propositions in the post-hoc provided pathophysiological explanations of the case.

Discussion

So far, some preliminary conclusions concerning our research questions can be drawn. First, our hypothesis that the application of biomedical knowledge decreases with increasing levels of expertise was confirmed, albeit after an initial rise between year two and four. The initial increase can be attributed to an increase in knowledge between year two and four. Second, investigation showed that this decrease is not caused by a decrease in availability of biomedical knowledge. Thus, we may conclude that the role of biomedical knowledge in expert clinical reasoning is virtually absent, while on the other hand this knowledge has not decayed. On the contrary, a steady growth of biomedical knowledge can be discerned.

Now the time had come to take the final, as yet unspecified step in our three step approach. This third step is needed in order to attain more insight in the organization of biomedical and clinical knowledge and in the mechanisms responsible for changes in the role and organization of clinical and biomedical knowledge.

Generally speaking two mechanisms can be hypothesized. The first possible explanation for this phenomenon is 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 any more. 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 second possible explanation of the results is based on Anderson's theory of the development of cognitive skills (Anderson, 1983). According to Anderson (1983), students first try to solve problems in a specific domain applying elaborate (in this case biomedical) knowledge. Successful application of this elaborate knowledge, consisting of a chain of propositions, results in its compilation 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.

In order to explore these two hypotheses, the overlap between applied and available knowledge was investigated. This amount of overlap was defined as the proportion of concepts in a subject's semantic network that were identical to any concept in the set of propositions derived from his or her think-aloud protocol. If biomedical knowledge becomes increasingly compiled with increasing expertise and is integrated in clinical knowledge, then a growing overlap of both kinds of knowledge is expected. If, however, biomedical knowledge becomes increasingly inert, no such increase in overlap is expected.

Overlap of think-aloud and post-hoc protocols

The proportion of concepts that appeared both in the post-hoc provided pathophysiological explanations and in the on-line applied knowledge varied with increasing levels of expertise ($F(3,29)= 14.977$, $p= .0001$). Figure 5 shows a monotonic increase with an increasing level of expertise. No effect of case typicality was found ($F(1,29)= 2.135$, $p= .1531$).

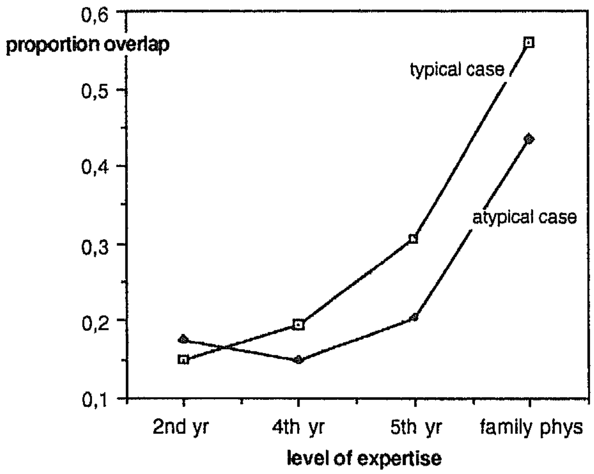

Figure 5. Proportion of common concepts in the think-aloud and post-hoc protocols

This finding contradicts the hypothesis that biomedical knowledge becomes increasingly inert and it is in agreement with the hypothesis of an increasing integration between biomedical and clinical knowledge. Hence, our analysis leads us to the conclusion that biomedical knowledge has not become rudimentary, nor inert, but instead becomes compiled and integrated in clinical knowledge.

Again the role of biomedical knowledge in clinical reasoning

Our results show that reasoning with clinical knowledge is preferred over biomedical knowledge in all levels of expertise. This observation does not disagree with our hypotheses. However, another observation does and that is the finding that our subjects applied *more clinical knowledge* in diagnosing an atypical case than in diagnosing a typical case. This finding was not expected, as biomedical knowledge was hypothesized to be needed for the explication of atypicalities in patient findings. In this paragraph we will try to explain this phenomenon.

For that reason we further investigated hypothesis generation and knowledge application in the think-aloud protocols (see table 1). These analyses showed no differences between the typical and atypical case in the moment the first hypothesis was brought forward (F(1,28)= .163, p= .6891), although this moment tended to vary with level of expertise (F(3,28)= 2.64, p= .0689). Especially fifth year students tended to 'postpone' hypothesis generation. They needed about ten more items than the other subjects before a first hypothesis was brought forward.

TABLE 1
Hypothesis generation and diagnosis in the typical and atypical case.

	2nd year students		4th year students		5th year students		physicians	
	typical case	atypical case	typical case	atypical case	typical case	atypical case	typical case	atypical case
item# first hypothesis	11	10.5	9.5	12.5	19.25	20	8	9.6
item# pancreatitis first mentioned	25.8	--*	21	48	23	34	8	19.2
diagnosis **	.2	0	.5	1.75	1.5	2	1.6	1.4

* No 2nd year student mentioned the hypothesis of pancreatitis in the think-aloud protocols in the atypical case.

** Subjects were asked to give a differential diagnosis. If pancreatitis was mentioned as a first possibility 2 points were given, if pancreatitis was not mentioned at all no points were given, otherwise 1 point was given.

There were, however, strong differences related to case typicality in the moment the correct hypothesis (typical or atypical) pancreatitis was first mentioned (F(1,28)= 13.169), p= .0011). When the subjects tried to diagnose the atypical case, there was a delay of 15 items on the average, before the hypothesis 'pancreatitis' appeared. In the typical case, all physicians considered pancreatitis as one of the possible diseases that might cause the patient's complaint. This first hypothesis set was brought forward when the complaint was presented (item# 8). The content of this set of first hypotheses was highly influenced by case typicality and it took the physicians about ten items more on the average to come up with the hypothesis 'pancreatitis' in the atypical case. This discrepancy was even bigger in the student groups. For instance, the fourth year students typically furthered their first hypotheses after the 11th item had been presented. That is after the complaint and two additional items. The hypothesis 'pancreatitis' was furthered eleven items later in the typical case, but in the atypical case this hypothesis was only brought forward after the (atypical) lab findings (in the last item) had been presented. These lab findings seem to have changed their hypotheses set completely as is suggested by the final diagnosis. Two of the four fourth year students reported pancreatitis as their final diagnosis, the other two students reported it as a good second possibility. The fifth year students were even more convinced by the lab findings. All of them reported pancreatitis as a first diagnostic possibility. Remarkably, these students concluded more often to the diagnosis 'pancreatitis' when the atypical variant had been presented than in the typical case. The physicians on the other hand found pancreatitis a less likely diagnosis in the atypical case.

These results indicate that the atypical case requires much more information before the right hypothesis is generated and before the diagnosis is arrived at. Furthermore, they suggest that the students' mental representation and the associated hypothesis sets of the atypical case are less stable than in case of the typical variant. Apparently, biomedical knowledge is not used to interpret and order this "*unstructured*" mass of case information. Instead, clinical knowledge seems to be preferred for information ordering and interpreting, while biomedical knowledge seems to be applied for a justification or explanation after the interpretation had been made.

An example of this way of reasoning is found in the think-aloud protocol of subject #4-15. After hearing the lab findings he concludes:

> "Serum amylase (32U) . increased .. that may indicate er a amylase is er . both er, let me think adrenaline amylase .. as ... hey wait a minute oh . wait that it just pops up .. the word pancreatitis .. er .. you don't have that that .. is specific for .. disease of the pancreas .. oh yes, sure alcohol .. the fact that er .. that pancreatitis is associated with alcohol consumption .. er yes high alcohol consumption .. that yes .. how was it exactly .. [some utterances about forgetting, having to study the subject again and not having thought of this hypothesis earlier] .. glucose 6.0 mmol/l. yes makes the pancreas more suspect .. if of course .. inflammation in the pancreas and er .. islets of Langerhans produce less insulin then . then of course a higher level of glucose remains [etc.]".

This example shows that first an item is clinically interpreted, while afterward a justification for this interpretation is construed. Most remarkably, this line of reasoning is set up to incorporate a finding that fits with the hypothesis generated. No such explanations are made in order to incorporate findings that do not really fit with the favorite hypothesis. This latter function for biomedical knowledge was however postulated. We must, however, keep in mind that in this experiment especially fourth year students applied biomedical knowledge. Nevertheless, the present findings raise the suspicion that theories that medical experts revert to biomedical knowledge when they have to diagnose a difficult case must at least be adjusted, if not completely reformed. As yet, however, the experimental results are not available to decide between these two options. An important prerequisite for this is to investigate medical experts solving difficult problems and applying biomedical knowledge in their own domain of expertise.

Conclusion

The presented experiment replicated the finding that (after an initial rise) the application of biomedical knowledge in clinical reasoning decreases with increasing levels of expertise. This decrease did not result from decay of biomedical knowledge. On the contrary, biomedical knowledge of the subject pancreatitis apparently increased with increasing levels of expertise. Furthermore, the analyses showed that biomedical knowledge had not become inert with increasing expertise. Finally, it was suggested that biomedical knowledge compiles and becomes increasingly integrated in the clinical knowledge base, resulting in a virtual absence of overt application of biomedical knowledge in the experts' think-aloud protocols.

Our theory on the role of biomedical knowledge in clinical reasoning was, however, complicated by two other findings. Biomedical knowledge was thought to be applied in order to accommodate deviating findings in the prevailing diagnostic hypothesis. The data did not support this assumption: Diagnosing the atypical case appeared to require more knowledge application propositions than the typical case, but, contrary to what was expected, an *equal* number of biomedical propositions was found. Differences in knowledge application resulted from an increase in the amount of clinical knowledge applied ($F(1,29) = 15.465$, $p = .0005$), while on top of that applied biomedical knowledge was used to explain why a matching instead of a deviating finding fitted with that hypothesis. Before any conclusions can be drawn from this result more specific research is needed.

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