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# Foundations of problem-based learning: some explanatory notes

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**Summary.** The present article elaborates on cognitive effects of problem-based learning put forward by Schmidt, De Volder, De Grave, Moust & Patel (1989) and Norman & Schmidt (1992). Its purpose is to discuss, in some detail, the theoretical premises of this approach to learning and instruction. It is argued that problem-based learning, above all, promotes the activation of prior knowledge and its elaboration. Evidence is reviewed demonstrating that these processes actually occur in small-group tutorials and that the processing of new information is indeed facilitated by discussion of a relevant problem. These effects must be attributed to a reorganization taking place in the knowledge structures of students as a result of problem-oriented study. In addition, a cognitive process called epistemic curiosity (or intrinsic interest) is enabled. Some directions for further research are outlined. The contribution starts, however, with a discussion of the philosophical and pedagogical roots of problem-based learning.

Key words: *education, medical, undergraduate; teaching/*methods; problem solving; learning; cognition

## Introduction

In the course of history, there has been a remarkable concurrence between the views of philosophers of science on the nature of the knowledge acquisition process within the sciences, and psychological theorizing on learning and instruction. Since the past century, when psychology broke free from contemplative philosophy and became an empirical science, this synchronicity could be observed time and again. If the issue was to explain how people obtain knowledge about their surrounding world, psychology has always moved to and fro between the two poles of empiricism and rationalism, just like philosophy of science. It may be useful to pay some attention to these two main trends in the philosophical discussion on the question of how people are able to know their world. Empiricism, advocated by the British philosophers Bacon, Locke and Hume, considers people to be empty slates ('*tabulae rasae*') on which nature writes down its laws. Scientists are expected to observe carefully and collect systematically data on reality, so that nature will eventually unveil its secrets. So, knowledge acquisition is in fact *inductive*; the repetition of events and the regularity with which phenomena appear, are, as it were, imposed on the careful observer as general laws of which the discovery is the goal of science. Contrary to this, rationalism presupposes that our knowledge of the world is primarily the product of our thinking activity. On the basis of a limited number of assumptions regarding reality, a theory can be developed to explain that reality by means of *deduction*. In this notion, theories are not so much systematic descriptions of reality derived from careful observations, but cognitive structures resulting from — in particular: logical — reasoning (Popper 1959).

Conceptions with regard to learning and instruction that have emerged rapidly through the impetus of Thorndike and Watson at the beginning of this century all carried the mark of

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behaviourism, an American branch of empiricism. However, at the fringe of this dominant tradition, stressing the influence of the environment in shaping the behaviours of learners, there has always been a school of thought, influenced by Kant and Descartes, believing that learning was mainly the result of a person's cognitive activity. Dewey (1929) has been a proponent of this point of view. In his view, knowledge cannot actually be 'transferred' but the learner has actively to 'master' it. The reason for this is that already available cognitive structures to be found in learners have to be engaged in the task of understanding new information and limit the extent to which they can understand new information. (The term 'cognitive structure' refers to knowledge stored in long-term memory. This knowledge is considered organized in a certain way; hence cognitive structure.) It is perhaps useful to give an example. Most readers have difficulty remembering a text such as the following, even if they spend considerable time studying it:

> 'Nobody tells productions when to act; they wait until conditions are ripe and then *activate* themselves. By contrast, chefs in the other kitchens merely follow orders. Turing units are nominated by their predecessors, von Neumann operations are all prescheduled, and LISP functions are invoked by other functions. Production system teamwork is more laissez-faire: each production acts on its own, when and where its private conditions are satisfied. There is no central control, and individual productions never directly interact. All communication and influence is via patterns in the common workspace — like anonymous "to whom it may concern" notices on a public bulletin board.' (Haugeland 1985)

It is, of course, possible to learn this text by heart, provided that enough time is available for repetition. The result of such activity, however, will probably not be what is usually considered real learning. An important component of actual learning is that the topic studied is *understood*. With the above text, this is difficult, because the issue constantly seems to escape the reader's understanding. Not all readers will have difficulty with understanding this text, though. People with a reasonably thorough knowledge of the computer sciences, and especially of artificial intelligence, will immediately have understood the text as an attempt to characterize various programming styles, and will be able to memorize such text almost effortlessly. Researchers and theoreticians within the rationalist tradition account for this phenomenon by assuming that people engage their prior knowledge of the subject in the act of comprehension of the text. Therefore, the amount of prior knowledge available determines to what extent something new can be learned. Those who lack relevant prior knowledge find it more difficult to understand and remember new information, because they have fewer 'tools' to construct a meaningful representation of what the text conveys.

Although some of these ideas have been thoroughly articulated in contributions by the French epistemologist Jean Piaget (1954) and by Jerome Bruner (1959), it is striking to see that they only became part of mainstream psychological theorizing after the pendulum within the philosophy of science once again swung from empiricism to rationalism at the beginning of the 1960s. From this perspective, Piaget and Bruner could be considered early heralds of the so-called 'cognitive revolution' in psychology.

Problem-based learning (PBL) as a method of instruction stands firm within the rationalist tradition and, hence, is strongly influenced by cognitive psychology (Norman & Schmidt 1992). Its roots can be traced in Dewey's (1929) plea for the fostering of independent learning in children and in Bruner's (1959, 1971) notion of intrinsic motivation as an internal force that drives people to know more about their world. In addition, the emphasis on active construction of theories about the world by students and on testing their hypothesized consequences deductively through literature review and discussion definitely has a rationalistic flavour. The role of problems as a starting point for learning can again be attributed to Dewey, who stressed the importance of learning in response to, and in interaction with, real-life events. In this article, the relationship between PBL and cognitive psychology, the current guise of rationalism, will be elaborated upon. The paper presents six fundamental principles of learning derived from the science of mind and discuss to what extent problem-based learning facilitates learning in accordance with these principles. Subsequently, a number of empirical studies will be discussed; studies conducted to clarify the nature of the learning process underlying PBL. Finally some items on the agenda for future research in this area will be outlined.

## Principles of cognitive learning

In the course of time, theoreticians and researchers have proposed a variety of learning principles (cf. Hilgard & Bower 1975). Recent developments suggest that those principles can be reduced to a relatively small set of theorems summarizing the state of the art in the area of learning. This small set of principles will be exemplified below.

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

This principle has already been exemplified through the computer science excerpt taken from Haugeland (1985). One of its implications is that the better students, those who have sufficient prior knowledge to profit from instruction, will learn more than those who have not, making the gap between the two groups wider as instruction proceeds. Another implication is that difficulty level of learning materials such as books or lectures cannot simply be understood as a function of the way in which the material is presented, but also has to do with the knowledge level of the audience for which the material is intended. The importance of prior knowledge level for instruction has been stressed again and again by educational psychologists, beginning with Ausubel in 1960, but has been largely ignored by educators (e.g. Ausubel 1968).

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

Bransford & Johnson (1972) presented experimental subjects with texts such as the following with the instruction to learn them by heart:

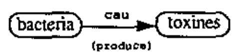
> 'A newspaper is better than a magazine. A seashore is a better place than the street. At first, it is better to run than to walk. You may have to try several times. It takes some skill but it's easy to learn. Even young children can enjoy it. Once successful, complications are minimal. Birds seldom get too close. Rain, however, soaks very fast. Too many people doing the same thing can also cause problems. One needs lots of room. If there are no complications, it can be very peaceful. A rock will serve as an anchor. If things break loose from it, however, you will not get a second chance.'

Subjects who studied texts such as this with an accompanying title (e.g. 'Making and flying a kite') remembered almost twice as much information as those who studied that same text without a title. Bransford & Johnson (1972) accounted for this phenomenon by assuming that both groups had cognitive structures available with respect to what is involved in flying kites, but that this knowledge is not activated by the text itself. The title does activate this knowledge, thereby creating a context through which new information could be related to existing knowledge, resulting in superior memory. The example given may seem quite exceptional. In regular educational contexts, however, many examples are documented in which learners do not seem able to relate new information to what they already know about a certain subject. Much research has been conducted especially with regard to science education (Caramazza *et al.* 1981; Champagne *et al.* 1983).

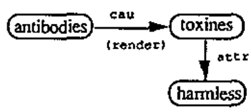
*(3) Knowledge is structured. The way in which it is structured in memory makes it more or less accessible for use*

How do psychologists imagine the knowledge structures responsible for much of human performance? Here is a definition: *Knowledge consists of propositions that are structured in semantic networks.* A *proposition* is a statement that contains two concepts and their interrelation. The following are examples of propositions within the field of medicine:

(1) Bacteria produce toxines




(2) Antibodies render toxines harmless



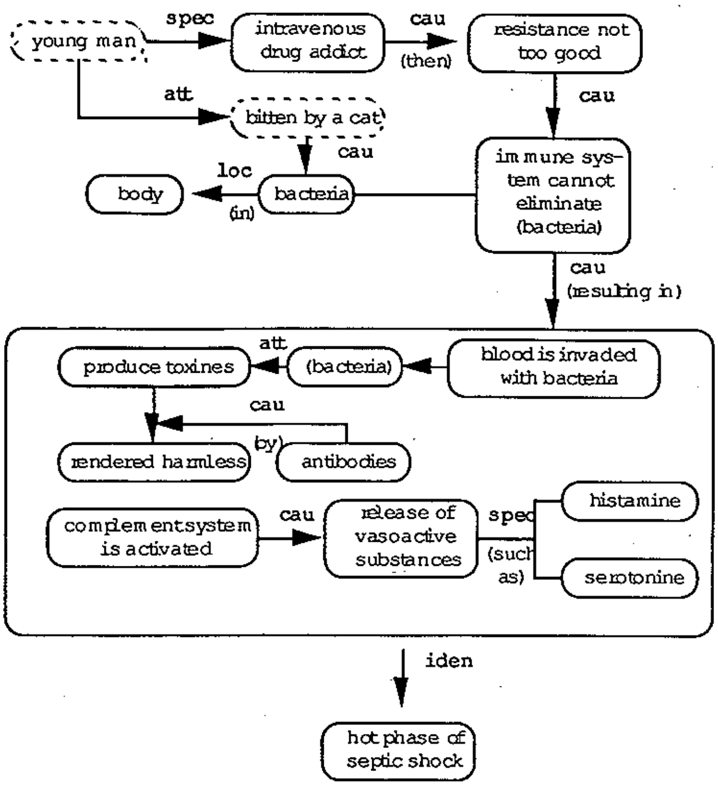



**Figure 1.** Part of a semantic network based on an explanation protocol produced by a fourth-year medical student. Links between concepts can be causal (cau), conditional (cond), temporal (temp), attributional (att) or locational (loc). In addition, they can indicate that the second node is a specification of the first (spec). Other qualifiers are: negative (neg), identity (iden) and class relation (isa). (Adapted from Schmidt & Boshuizen 1993.)

The special notation derived from Patel & Groen (1986) makes it easy to display knowledge as networks of concepts and their interrelations. Thus, semantic networks consist of large numbers of propositions such as these, relating to each other in a web-like fashion. They are entirely idiosyncratic, that is no two subjects have exactly the same knowledge about a certain topic. Semantic networks impose structure upon reality which otherwise would be perceived as an undifferentiated mass. These structures do not necessarily represent reality accurately; in fact gross departures from reality are often observed in students. What is important to note is that they provide the means to understand the world. The depth and accuracy of comprehension is a function of the quality of these structures. Knowledge structured in semantic networks should therefore not be confused with book knowledge as such. It is, in fact, a reflection of a person's experiences, views and ideas. Figure 1 shows part of a semantic network produced by a fourth-year medical student while trying to make sense out of a clinical case of a young drug addict who may have been bitten by a cat and develops a septic shock.

The amount of detail of such a knowledge structure, the number of relations between concepts and the way in which it is organized, will influence what can be *done* with that knowledge. One of the reasons, for instance, that students seem to be unable actually to use in a clinical setting what they have learned previously through books and lecturers is that their knowledge is not yet organized in a way suitable for the kind of tasks required of them in that setting. It is generally assumed that the necessary restructuring of the knowledge base only takes place in response to the demands of the tasks posed.

*(4) Storing information into memory and retrieving it can be greatly improved when, during learning, elaboration on the material takes place*

Anderson & Reder (1979) were the first to demonstrate the elaboration principle in an experiment. In this experiment, they used a classical psychological research paradigm, the paired-associate task. This task resembles learning word pairs in foreign language instruction. The second word of the pair, however, is not the foreign language associate but a word in the same language. The task of the learner in paired-associate experiments, thus, is to learn the association between the two — unrelated — words in the same language. The following are a few examples:

| | |
|---|---|
| dog | bike |
| bird | school |
| chair | flower |
| man | house |

The task is that the experimental subjects are to learn these pairs and in such a way that when the experimenter presents the first word, 'dog', the subjects recall 'bike'. Anderson & Reder instructed half of the group to learn a list similar to the above example (but of course much longer). The other half was to do the same yet was instructed to establish actively a relationship between the two elements of a pair. For instance, in learning the pair 'dog–bike' it was suggested that the subjects imagine a dog on a bike. Subjects instructed to follow this learning strategy performed considerably better on a recall test than the control group. Anderson & Reder call this active way of dealing with learning material 'elaboration', because the learner expands on the relation between two concepts. According to these investigators, this approach is so successful because elaboration of the resulting network of propositions creates multiple redundant retrieval paths. This facilitates the retrieval of a concept from memory; the availability of more than one path enhances the probability that a concept will be retrieved.

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

This principle, too, can perhaps best be explained by means of an illustrative study. Godden & Baddeley (1975) instructed professional divers to learn lists of words in a paired associate task, similar to Anderson's & Reder's (1979). Half of this group learned the list under water in a pool, whereas the other half worked near the pool. Subsequently, half of the subjects studying under water were taken out of the pool and half of those near the pool were placed into the water. Finally, all subjects were requested to recall as many paired words as possible. The results clearly showed that those subjects who performed the memory task *in the same environment* as in which they had learned the word list performed considerably better than those who had to retrieve the information in an environment other than the one in which they had learned the list. This experiment shows that information intentionally learned and incidental information about context are simultaneously stored in a person's memory (even if the context is absolutely irrelevant to the learning task, as in the pool case). Availability of the same context at a future point in time facilitates retrieval of the information. This phenomenon is called the contextual dependency of learning. It can be observed in many situations; from failing to find the right answers in an examination room although the subject matter had been carefully studied at home, to finding out that one has to review much of medicine simply because the appropriate knowledge is not activated while seeing patients (as happens to many medical students when entering the clerkships).

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

Someone who feels the urge to learn will in general be prepared to spend more time on learning than someone who feels less inclined. Hence, a relation between the time spent on processing subject matter and achievement may be expected. In the literature, a distinction is made between two types of drive, or motivation:

intrinsic and extrinsic motivation. Intrinsic motivation is generally considered a kind of curiosity that drives the subject into knowing more about a topic. Therefore, it is sometimes called 'epistemic curiosity' or intrinsic interest. It is assumed that this drive is entirely internally propelled without external rewards. Extrinsic motivation, on the other hand, is characterized by the fact that subject matter is studied, not as a goal in itself, but to achieve other objectives, such as passing an examination, obtaining a degree certificate, increasing self-confidence, or having a well-paid job. Here, knowledge acquisition has a means–end function. In the present paper we are only interested in the role of epistemic curiosity in learning new information.

A study conducted by Johnson & Johnson (1979) clearly illustrates the effects of epistemic curiosity. They instructed small groups of children to study texts that either described the economic necessity of surface coal-stripping, or rejected surface coal-stripping because of the damage done to the environment. Children that had studied one of these texts were subsequently required to try to convince others who had studied the other text in a small-group discussion. Compared with a group of subjects that had studied the texts individually, those who had discussed the controversial issue spent more time studying additional information and watched a documentary about the topic more often. According to Johnson & Johnson, they had become intrinsically interested in the subject due to the controversy discussion. This experiment and others (e.g. Lowry & Johnson 1981) demonstrate that group discussion aimed at clarifying one's own point of view and being confronted with other perspectives stimulates epistemic curiosity in subject matter.

To what extent do these principles of learning apply to problem-based learning? We will deal with this question in the next section.

## Problem-based learning: analysis of the learning process

Problem-based learning was originally developed at the Faculty of Health Sciences of McMaster University around 1965. Its originators, among them John Evans, Bill Spaulding, Bill Walsh, Jim Anderson and Fraser Mustard (see Spaulding 1991), were influenced by the case-study method as developed at Harvard Law School in the 1920s (Fraser 1931). In particular the use of cases as an instrument for learning was considered appealing (personal communication, Dr Vic Neufeld). Howard Barrows, a neurologist who arrived at McMaster at the end of the 1960s became a major proponent of the approach (Barrows 1984; Barrows & Tamblyn 1980).

Problem-based learning is an approach to learning and instruction in which students tackle problems in small groups under the supervision of a tutor. In most of the cases, a problem consists of a description of a set of phenomena or events that can be perceived in reality. These phenomena have to be analysed or explained by the tutorial group in terms of underlying principles, mechanisms or processes. The tools used in order to do that are discussion of the problem and studying relevant resources. An instance is the following problem:

*Tea for two*

On a nice day in the summer Henry (5 years old) returns from school and would like to have a cup of tea. The tea is soon made and poured, but by accident Henry gets the hot tea over his bare leg. Although his mother immediately holds the screaming Henry under a gentle jet of cold running water, his leg looks badly affected; he has burst blisters and the entire anterior side of his thigh is quite red. The doctor takes care of the wound and asks Henry to come to surgery the next day. Because the wound is patchy and locally covered with a whitish coating, Henry is then referred to the hospital. Despite optimal care, part of the wound (approx. $10 \times 10$ cm) has still not healed completely after three weeks.

Medical students given the problem to consider are led to the structure and functioning of the skin, to study the effects of severe burning of the skin and to understand the mechanisms of pain in such a case. On the other hand, a problem such as the following:

*Playing tennis*

You've been playing a game of tennis among friends. It is a warm and sunny day. Unfortunately, you lose the exciting game. When you walk home, you notice that you are wet all over your body, your face feels hot and looks scarlet and your leg muscles begin to ache.
Please explain.

would induce students to study in depth the physiology of effort including thermoregulation. Students are trained to deal with such a problem first by activating available prior knowledge. Therefore the problem is discussed first without reference to the literature (Barrows & Tamblyn 1980; Schmidt 1983a).

Goals of this preliminary discussion are fourfold. First, it will help students mobilize whatever knowledge is already available. The importance of activation of prior knowledge in the comprehension of new information has already been stressed. Activation of prior knowledge focuses the learning effort and facilitates the understanding of new concepts to be mastered. If appropriate knowledge is not activated for some reason, new learning will not take place or will be seriously hampered. Second, group discussion will help students to elaborate on their knowledge. The confrontation with the problem to be understood and other students' knowledge of what might explain the phenomena will lead to enrichment of the cognitive structures of the participants. Third, the knowledge already available at this point becomes tuned to the specific context provided, that is the problem posed. Thus, some knowledge restructuring may already take place at this point. Fourth, the discussion of a problem is supposed to engage the students in the subject to such extent that epistemic curiosity is aroused to find out in more detail which processes are responsible for the phenomena described.

While discussing the problem, students may encounter issues not well understood. If the problem is tuned to the level of prior knowledge of the particular group of students, they may have some understanding but will soon run into questions that need answers in order to acquire a deeper level of comprehension of the problem. These questions serve as learning goals to be pursued through self-directed learning. Thus, students will review textbooks, articles and other resources in order to build a more comprehensive semantic network of the problem-at-hand. In a second round of discussions, students will check to what extent they now have a more in-depth, more differentiated, understanding of the problem. This discussion may lead to further elaboration, restructuring and fine-tuning.

Central to the theory proposed here is that students while thinking, studying and talking about the particular problem build a context-sensitive cognitive structure of the processes, principles or mechanisms underlying the visible phenomena, which may help them understand more complex problems presented subsequently and which in the final analysis may support the management of these problems when encountered in professional practice. The construction of such semantic networks, tuned to the situation-at-hand, is the goal of PBL.

In summary, it is proposed here that PBL as an approach to learning and instruction has the following cognitive effects on student learning:

(1) Activation of prior knowledge — the initial analysis of a problem stimulates the retrieval of knowledge acquired earlier.

(2) Elaboration on prior knowledge through small-group discussion, both before or after new knowledge has been acquired; active processing of new information.

(3) Restructuring of knowledge in order to fit the problem presented. Construction of an appropriate semantic network.

(4) Learning in context. The problem serves as a scaffold for storing cues that may support retrieval of relevant knowledge when needed for similar problems.

(5) Since students will tend to see the problems presented as relevant and since they engage in an open-ended discussion, epistemic curiosity can be expected to emerge.

## Problem-based learning: research into the basic premises

The question which of course immediately arises is to what extent these premises regarding the cognitive processes underlying problem-based learning have an empirical basis. In this section a number of studies will be discussed conducted by the research group on 'Cognitive and Motivational Effects of Problem-based Learning' of the University of Limburg. (This group consists of Jan Beliën, Maurice de Volder, Willem de Grave, Jos Moust, Bert Kerkhofs, Henk Schmidt, Steve Foster, Rite Dobbelaere, Herman Nuy and Titus Geerlings.) These studies have been published in Dutch or have otherwise been poorly accessible to the international health professions education community. In this discussion, we will confine ourselves to the results of the so-called 'blood-cell-problem studies'.

*Activation of prior knowledge.* Schmidt (1984) presented small groups of students attending higher professional training with the following problem: 'A red blood cell is put in pure water under a microscope. The cell swells and eventually bursts. Another blood cell is added to an aqueous salt solution. It shrinks. Explain these phenomena.' A few years prior to this study, the students involved had all been acquainted with the subject of osmosis, which is the underlying explanatory mechanism for the phenomena described in the problem. Half of the students discussed the blood-cell problem, while the other half discussed a neutral problem. At a subsequent 'free-recall' test, the group that had discussed the blood-cell problem remembered almost twice as much information about osmosis as the other group. (Free recall is a procedure in which a subject is instructed to write down everything that he or she remembers about a certain topic without the aid of further information. It is considered a measure of both amount and coherence of the knowledge a subject has.) This demonstrates that problem analysis in a small group indeed has a strong activating effect on prior knowledge.

*Effects of prior knowledge activation on the processing of new information.* Schmidt *et al.* (1989) presented the blood-cell problem to novices, 14-year-old high-school students who had never heard of the subject concerned. Their explanations therefore mainly had a common-sense character. In an attempt to account for the swelling of the blood cell, one group assumed that the membrane probably had valves which would let the water in, but would prevent it from escaping again. Another group explained the shrinking of the cell by assuming that salt has hygroscopic characteristics. According to them, the salt 'soaked up' fluids from the cell in the way that it would with a wine-stained table-cloth. (See also Table 1.) Subsequently, a 6-page text about osmosis was distributed, both to the groups that had tackled the blood-cell problem and a control group that had discussed a neutral topic. The group that had discussed the blood-cell problem prior to reading the text remembered significantly more about the text than the group that had studied an unrelated topic. These findings indicate that activation of prior knowledge through problem analysis in a small group definitely facilitates understanding and remembering new information, even if that prior knowledge is only to a small extent relevant to understanding the problem — and sometimes even incorrect. Interestingly, students who studied the topic of osmosis a few weeks before the experiment was conducted (called the 'experts' by the authors) did not profit as much by the experimental treatment as compared to the novices, indicating that problem analysis is most helpful if students have only limited knowledge of the subject.

*Contribution of group discussion to the effect of problem-based learning.* De Grave *et al.* (1985) have compared effects of problem analysis in a small group with individual problem analysis and direct prompting of knowledge about osmosis. They discovered that small-group analysis had a larger positive effect on remembering a text than individual problem analysis. Prompting already available knowledge relatively had the smallest effect. The investigators concluded that the confrontation with a relevant problem and small-group discussion of that problem each have an independent facilitating effect on prior knowledge activation relative to direct prompting of prior knowledge. Group discussion had, in particular, a considerable effect, suggesting that elaboration on prior knowledge and learning from each other, even before new information is acquired, are potent means to facilitate understanding of problem-relevant information. Moust *et al.* (1986) demonstrated that the quantity of one's contribution to the discussion and its quality were unrelated to achievement. This led them to the conclusion that the more silent students were involved in what they called 'covert elaboration'. According to these authors it would otherwise be hard to understand how these students would profit from the experience.

*Evidence for elaboration and restructuring processes.* To date no data are available which document the emergence of problem-oriented knowledge structures as a result of PBL, that is a result of problem discussion *plus* individual study. There is, however, some evidence for problem-oriented knowledge tuning as a result of problem analysis *per se.* Table 1 summarizes explanations of secondary-education students regarding the blood-cell problem.

**Table 1.** Naive conceptions of processes that are the basis of the blood-cell problem (taken from Schmidt *et al.* 1988)

*Swelling*
- (1) The cell is filled with tiny sponges absorbing the water.
- (2) The cell absorbs water by means of an unidentified mechanism because the wall is porous. However, the wall contains valves that prevent the water from escaping.
- (3) Red blood cells carry oxygen. The cell extracts oxygen from the water and swells.
- (4) The cell contains salts dissolved in liquid. The solution exerts pressure on the wall larger than the outside pressure exerted by pure water.
- (5) The absorption of water triggers an unknown chemical reaction within the cell.

*Bursting*
- (6) Blood cells usually take in small quantities of liquids, because the human body contains many cells. In this particular case, there is only one cell, which has to absorb too much water.
- (7) Animate objects only have a limited life-span.

*Shrinking*
- (8) Water on other fluids is extracted from the cell because of the hygroscopic properties of salt.
- (9) Salt water exerts a higher pressure on the wall than the content of the cell.
- (10) The salt corrodes the wall by affecting the wall's molecules. The cell then begins to leak.
- (11) The salt enters into the cell and digests the cell from within.

*Swelling and shrinking in combination*
- (12) The cell contains salt that extracts water from its environment because of its hygroscopic properties. If the water in the environment contains a higher concentration of salt, however, fluids will be extracted from the cell.

These explanations were compiled from taped discussions of six groups (some groups produced several explanations). These explanations suggest that students adapt their general prior knowledge to fit the problem-at-hand. The subjects involved had never before been confronted with a similar problem; therefore the assumption that general world knowledge is indeed restructured in order to make it suitable for the problem presented does not seem farfetched.

*Effects of problem-based learning on epistemic curiosity.* In a series of studies by De Volder and his colleagues (e.g. De Volder *et al.* 1985, 1989), attempts have been made to find out to what extent group discussion about a problem would increase epistemic curiosity in problem-related subject matter. Groups were presented with either the blood-cell problem or with a problem description of a plane taking off from Schiphol Airport. Immediately after the discussion, they were asked to indicate to what extent they were interested in receiving information about osmosis. After having studied a text on the subject, they were asked whether they would like to read more about the subjects and whether they were interested in additional information sent to them by the investigators. Before as well as after having studied the texts, the groups that had tackled the blood-cell problem displayed significantly larger epistemic curiosity than the group that had studied the aeroplane problem. Schmidt (1983a) found that this higher epistemic curiosity showed itself, among other things, in the fact that significantly more students participating in the blood-cell discussion had signed up to attend a lecture about osmosis than those who had not participated in that discussion.

## Discussion

Problem-based learning is a relatively new form of instruction with a long intellectual history. Its roots in the philosophies of rationalism and American functionalism (Dewey 1929) clarify why this approach to learning and instruction emerged in conjunction with the cognitive revolution in psychology. It is not purely coincidental that McMaster University admitted its first batch of medical students in its problem-based curriculum a year before Ulric Neisser's now classic book *Cognitive Psychology* was published (Neisser 1967). We have argued that in PBL, a number of principles of learning are implemented, considered to be basic to many forms of human learning, comprehension and problem-solving. These principles can be summarized as: prior knowledge activation and elaboration through small-group problem analysis; the construction of problem-oriented semantic networks, including contextual cues derived from professionally relevant problems; and the fostering of epistemic curiosity.

A number of studies have been reviewed that provide empirical support for the assumptions underlying PBL. The activation of prior knowledge through small-group discussion now seems to be a well-established phenomenon. The same applies to the effects of PBL on epistemic curiosity. There is, however, a need for further studies on what exactly goes on in a group tackling a problem. What are the kind of ideas cropping up during group discussion? Where do they come from? Do students actually construct new ideas while elaborating on a problem? What do students think while being involved in a discussion? What is the role of misconceptions expressed or even developed during these initial discussions? Do they survive subsequent individual study? Is the resulting semantic network indeed problem-oriented? Does it contain references to the original problem? Does it help students in better understanding and solving similar problems? And finally: Is it possible to deduce principles for effective problem design? Laboratory experimentation under strict control of extraneous variables is needed to find answers to these questions.

Although laboratory experiments such as the blood-cell studies are vital to our understanding of PBL and, hence, to its further development, it should be stressed that experiments also have their limitations. They require control over variables that one might want to study in their own right, such as what students read while involved in self-study, the nature of additional learning activities, how much time students spent on learning, etc. It is necessary therefore to supplement laboratory research with studies in natural contexts. The University of Limburg research group has made several attempts in this area (Dolmans *et al.* 1992; Kokx & Schmidt 1992; Moust & Schmidt 1992). For an overview see Nooman *et al.* (1990). Others are also leading the way (e.g. Moore 1991; Blumberg & Michael 1992).

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