Foundations of Problem-Based Learning – Some Explanatory Notes[1]

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Abstract: In this article theoretical premises of problem-based learning are discussed. It is argued that this approach to learning and instruction facilitates the activation of prior knowledge and its elaboration. In addition, problem-based learning is supposed to support the emergence of problem-oriented cognitive structures in students. Thirdly, it fosters intrinsic motivation. Empirical evidence relevant to these claims is reviewed.

Introduction

In the course of history, there has always been a remarkable similarity 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, the occurrence of 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. This is how behaviourism emerged in a time when positivism dominated philosophy of science. On the other hand, the cognitive revolution in psychology in the fifties and sixties coincided with growing uncertainties about the validity of logical positivism as an epistomology and the emergence of critical rationalism by Popper, Lakatos and others (Popper 1959).

It may be useful to pay some attention to the two main trends in the philosophical discussion on the question of how people are able to know their world. Empiricism, advocated by the British theoreticians Bacon, Locke and Hume, considers people to be empty slates („tabulae rasae") on which nature writes down its laws. Scientists are expected to carefully observe and systematically collect 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, is – 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. To phrase this caricaturally: Whereas the empiricist mindlessly takes notes dictated by nature somewhere in the field, the rationalist sits at home turned inward, contemplating the essence of things.

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 behaviourism, an American branch of empiricism. Behaviourism imposed severe restrictions on what was to be the object of psychology. According to the early behaviorists, only observable behaviour would lend itself to scientific analysis. In this view, theories of learning could only deal with principles regulating the acquisition of behaviours and the external stimuli under which changes in behaviour occur. The basic ingredients of the learning process were excercise, repetition and reinforcement of desirable behaviour. Instruction, especially those instructional methods that were justified by these views, would therefore strongly focus on drilling students through continuous repetition. Examples are: Droning the tables from 1 to 10 in arithmetics instruction, rehearsing the names of cities and other geographical facts during geography lessons and learning anatomical nomenclature by heart through recitation. Technological advances such as programmed instruction were based on the same principles. The pupil or the student was considered to be a tabula rasa and it was the task of the teacher, the learning book or curriculum to fill that blank page by „transferring" knowledge as efficiently as possible. Lectures for large groups and machine-mediated instruction could comply with that requirement.

However, at the fringe of this dominant tradition, stressing the influence of the environment in shaping the behaviours of learners, there always has been a school of thought, influenced

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by Kant and Descartes, believing that learning was mainly the result of a person's cognitive activity. Dewey (1929) has been a articulate proponent of this point of view. In his view, knowledge cannot actually be „transferred" but the learner has to actively „master" it. The reason for this is that already available cognitive structures[2] to be found in a learner have to be engaged in the task of understanding new information um and limit the extent to which he can understand new information. 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 to 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 characterise various programming styles, and will be able to memorise such text almost effortlessly. Researchers and theoreticians within the rationalist tradition account for this phenomenon by assuming that a person engages his 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 than those who do have adequate prior knowledge.

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

Problem-based learning as a method of instruction[3] 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 the person to know more about his 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 again can 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 problem-based learning and cognitive psychology, the current guise of rationalism, will be elaborated upon. We will present five 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 problem-based learning. Finally an 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. Hillgard and 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.

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

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[2] The term „cognitive structure" refers to knowledge stored in long-term memory. This knowledge is considered organised in a certain way; hence cognitive structure.

[3] Problem-based learning as a knowledge acquisition activity is described in more detail in section 3 of this article.

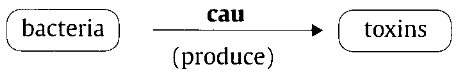
„A newspaper is better than a magazine. A seashore is a better place than the street. At first, it is better to run than to walk. You may have to try several times. It takes some skill but it's easy to learn. Even young children can enjoy it. Once successful, complications are minimal. Birds seldom get too close. Rain, however, soaks very fast. Too may 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 and 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).

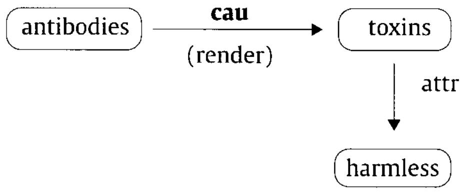
3. *Knowledge is structured. The way in which it is structured in memory makes it more or less accessible for use*

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.

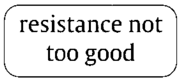


2. Antibodies render toxines harmless.

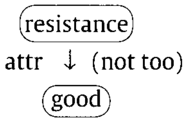


The special notation derived from Patel and Groen (1986) makes it easy to display knowledge as networks of concepts and their interrelations. Thus, semantic networks consist of large numbers of propositions such as these, relating to each other in a web-like fashion. They are entirely idiosyncratic; that is: no two subjects have exactly the same knowledge about a certain topic. Semantic networks imposes 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 a 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.

To increase readability, some propositions have been rendered concepts such as



which normally would have been represented as



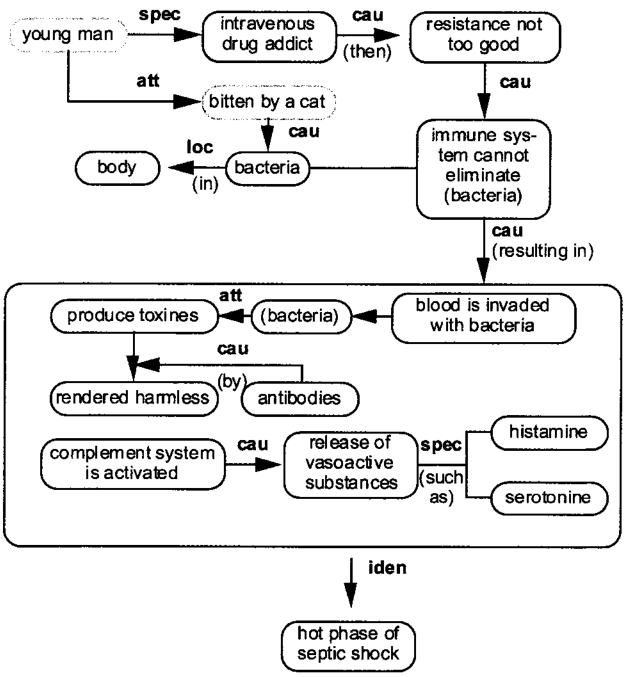


Fig. 1 Part of a semantic network based on an explanation protocol produced by a fourth-year medical student. Links between concepts can be causal (cau), conditional (cond), temporal (temp), attributional (att) or locational (loc). In addition, they can indicate that the second node is a specification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

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 to actually use in a clinical setting what they have learned previously through books and lectures, is, that their knowledge not yet is organized in a way suitable for the kind of tasks required from 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. It is therefore important that medical students are exposed to clinical cases early in their training so that restructuring and tuning of the knowledge base can begin to take place as soon as possible.

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

Anderson and 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:

Table 1 Some examples of paired-associates.

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 and 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 actively establish a relationship between the two elements of a pair. For instance: In learning the pair „dog-bike" the subjects were suggested to 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 and 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 and Baddeley (1975) instructed professional divers to learn lists of words in a paired associate task, similar to Anderson's and 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 much 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 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, there is a linear relation between the time spent on processing subject-matter and achievement. 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. It is assumed that this drive is entirely internally propelled without external rewards. Extrinsic motivation, on the other hand, is characterised 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 acquistion has a means-end function. In the present paper we are only interested in the role of intrinsic motivation in learning new information.

A study conducted by Johnson and Johnson (1979) clearly illustrates the effects of intrinsic motivation. 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, subsequently were required to try 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 that had discussed the controversial issue, spent more time on studying additional information and watched a documentary about the topic more often. According to Johnson and Johnson, they had become intrinsically interested in the subject due to the controversy discussion. This experiment and those of 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 intrinsic interest 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 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. For instance, the following problem:

The 55-year old woman
A 55-year old woman lies on the floor crawling of pain. The pain emerges in waves and extends from the right lumbar region to the right side groin and the front of the right leg.
How can these phenomena be explained?

would lead medical students into the structure and functioning of the urogenital system, study the emergence of kidney stones and understand the mechanisms of pain in a case like this. 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. So, the problem is discussed first without reference to the literature (Barrows and Tamblyn 1980, Schmidt 1983a). Goals of this preliminary discussion are fourfold. First, it will help students mobilizing whatever knowledge is already available. We have already stressed the importance of activation of prior knowledge in the comprehension of new information. Activation of prior knowledge focuses the learning effort and facilitates the understanding of new concepts to be mastered. If appropriate knowledge for some reason is not activated, new learning will not take place or 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 intrinsic motivation 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 soon will 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 text-books, articles and other resources in order to built a more comprehensive semantic network of the problem-at-hand. Intrinsic interest may lead the way, determining what will be studied and to what extent. 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 in 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, that may help them understanding more complex problems presented subsequently and 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[4] is the goal of problem-based learning.

In summary, it proposed here that problem-based learning 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. Students perceive the subject to be learned as being relevant.
6. Since students themselves are responsible for what has to be learned and how, the intrinsic motivation to learn increases. Intrinsic motivation is also increased by discussing problems, because when people get involved in a subject, they want to know more about it.

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[5]. The-

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[4] These structures are sometimes called „situation models" (Van Dijk and Kintsch 1983) to delineate their context-dependent nature. They are thought to play a decisive role in all human expertise-related tasks.

[5] This group consists of Jan Beliën †, Maurice de Volder, Willem de Grave, Jos Moust, Bert Kerkhofs, Henk Schmidt, Steve Foster, Rita Dobbelaere, Herman Nuy and Titus Geerlings.

se 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 all had 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[6], the group that had discussed the blood-cell problem remembered almost twice as much information about osmosis as the other group. 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, fourteen-year old high school students that had never heard of the subject concerned. Therefore, their explanations 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 **2**). Subsequently, a six-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 a 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 for 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.

Table 2 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, that has to absorb too much water.
7. Animate objects only have a limited life-span.

Shrinking

8. Water or other fluids are 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.

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.

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[6] 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.

Evidence for elaboration and restructuring processes

To date no data are available documenting the emergence of problem-oriented knowledge structures as a result of problem-based learning; that is: as 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 **2** summarizes explanations of secondary-education students regarding the blood-cell problem.

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 intrinsic motivation

In a series of studies by De Volder and his colleagues (e.g., De Volder et al. 1986 and 1989), attempts have been made to see to what extent group discussion about a problem would increase intrinsic interest 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 the airport of Schiphol. 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 intrinsic motivation than the group that had studied the aeroplane problem. Schmidt (1983b) found that this higher intrinsic motivation 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. Interestingly, intrinsic motivation was not directly related to achievement but rather seemed to be an independent outcome of the learning process.

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 problem-based learning 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 intrinsic motivation.

We have reviewed a number of studies that provide empirical support for the assumptions underlying problem-based learning. The activation of prior knowledge through small group discussion now seems to be a well-established phenomenon. The same applies to the effects of problem-based learning on intrinsic motivation. 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 popping up during groups 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 problem-based learning 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, therefore, necessary 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, Moust and Schmidt 1992, Kokx and Schmidt 1992. See for an overview Nooman et al. 1990.) Others are leading the way as well (e.g. Blumberg and Michael 1992, Moore 1991).

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