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Problem-based learning: rationale and description

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Summary

Problem-based learning is an instructional method that is said to provide students with knowledge suitable for problem solving. In order to test this assertion the process of problem-based learning is described and measured against three principles of learning: activation of prior knowledge, elaboration and encoding specificity. Some empirical evidence regarding the approach is presented.

Key words: TEACHING/*methods; *PROBLEM SOLVING; LEARNING; EDUCATION, MEDICAL, UNDERGRADUATE

Introduction

In the medical education literature the concept of problem-based learning is presented as a useful instructional alternative to conventional procedures. It has been suggested that problem-based learning may solve some pertinent problems of medical education, such as the irrelevance of some of the knowledge which students have to acquire in traditional curricula, the lack of integration of subject-matter from different medical disciplines and the need for continuing education after graduation. (Barrows & Tamblyn, 1980; Neame, 1981; Neufeld & Barrows, 1974; Schmidt & Bouhuijs, 1980). One other problem that, so far, has attracted less attention pertains to the inability of students to make appropriate use of what they have learned. In a controlled trial Gonella *et al.* (1970) found that doctors and residents of a large general hospital were in 50% of cases unable to perform critical screening activities on patients that were suspected to have pyelonephritis. When tested on this subject by means of multiple-choice questions this same group performed quite well. Their mean score on this test was equal to 82%.

Other examples can be drawn from the non-medical educational literature. Driver & Easley (Anderson, 1977) conducted research among high school physics students. Interviews were conducted regarding the movements of balls along a horizontal track. According to Driver & Easley many of the students manifested 'an Aristotelian notion that constant force is required to produce constant motion . . . while they used the language of Newtonian mechanics, such as force, momentum, impulse, etc'. These students were acquainted with the concepts of modern mechanics, but were unable to use them in understanding real-world phenomena. Willems and his co-workers (Willems, 1978; 1981) established essentially the same phenomenon in investigations among students of law, social geography, planning science and sociology. When writing a report on some topic or solving problems, these students seem to be unable to use the knowledge they had acquired.

The main conclusion that has to be drawn from these results is that people can possess knowledge which they seem unable to apply. They know information but cannot use it. This conclusion is in accordance with findings in educational psychology. Mayer & Greeno (1972) for instance, show that different instructional methods produce different learning outcomes. The way in which a topic is taught determines what students can do with the information acquired. In short, conventional instruc-

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tional procedures do not always enable students to make appropriate use of their knowledge, e.g. to solve problems.

The question arises whether problem-based learning, as an instructional method that evolved out of the needs of professional practice (Barrows & Tamblyn, 1980), is more suitable for this task than traditional education. In order to be able to give a provisional answer to this question, comment will first be made in general about conditions that foster human learning. Next the process of problem-based learning will be described in some detail with reference to the preceding remarks. Finally some of the effects of the problem-based learning approach will be reported.

Three conditions that facilitate learning

In order to be able to evaluate the characteristics of problem-based learning a frame of reference is needed. It can be provided by the information processing approach to learning (Anderson, 1977). According to this theory three principles play a major part in acquiring new information: activation of prior knowledge, encoding specificity and elaboration of knowledge.

(1) The role of prior knowledge in learning will be discussed. Learning, by its nature, has a restructuring character. It presupposes earlier knowledge that is used in understanding new information. For instance, by studying an article about defence mechanisms against infections, a student applies knowledge he already possesses in order to understand the new information. A first-year medical student, while reading and interpreting the article, will probably make use of his secondary-school knowledge of biology, perhaps supplemented with common sense knowledge on bacteria, viruses, influenza and vaccinations. A fourth-year student, in studying that article, will use his immunological and microbiological knowledge, acquired earlier. This prior knowledge and the kind of structure in which it is available in long-term memory, will determine what is understood from the article and this, in turn, will define what is learned from it (Rumelhart & Ortony, 1977). This relationship between prior knowledge and learning could be demonstrated with first- and fourth-year medical students, who read the same article and have the same amount of reading time available to process it. The fourth-year students will show better learning results because their more elaborated prior knowledge will enable them to process the new information more easily. Experimental evidence for this assertion is provided by Dooling & Lachman (1971) and Bransford & Johnson (1972). Instructional methods, however, differ in their capacity to induce activation of relevant prior knowledge (Mayer & Greeno, 1972). Only in as far as they help students in activating relevant knowledge they will facilitate the processing of new information (Mayer, 1982).

(2) The second condition that facilitates learning has been derived from the work of Tulving & Thomson (1973). They state that successful retrieval of information on some point in the future is promoted when the retrieval cues that are to reactivate the information are encoded together with that information. In other words, the closer the resemblance between the situation in which something is learned and the situation in which it is applied, the better the performance. This phenomenon is called encoding specificity. It is practiced during clinical lectures or clerkships, where students acquire knowledge related to patient problems that have characteristics in common with what students will encounter in later professional life.

(3) The third condition has to do with elaboration of knowledge. Only recently did psychologists discover that information is better understood, processed and retrieved if students have an opportunity to *elaborate* on that information (Anderson & Reder, 1979). In education there are many ways in which this condition is fulfilled. Students can elaborate on information by answering questions about a text (Anderson & Biddle, 1975), by taking notes (Peper & Mayer, 1978), by discussing subject matter to be learned with other students (Rudduck, 1978), by teaching peers what they have first learned themselves (Bargh & Schul, 1980), by writing summaries (Wittrock, 1974), and by formulating and criticizing hypotheses about a given problem (Schmidt, 1982). According to Reder (1980) elaborations provide redundancy in the memory structure. Redundancy can be viewed as a safe-guard against forgetting and an aid to rapid retrieval.

In conclusion, in order to optimize learning, education should help students in activating relevant prior knowledge, provide a context that resembles the future professional context as closely as possible, and stimulate students to elaborate on their knowledge. If one or more of these conditions are not met, the quality of instruction will suffer.

Problem-based learning: description of the process

To assess the extent that problem-based learning meets the requirements stated above, it is necessary to take a closer look at it. That will be done using an example borrowed from Schmidt & Bouhuijs (1980).

The process of problem-based learning starts with a problem such as the following:

A plumber sees his doctor with the following complaint:
'During a hard cough this morning I suddenly tasted blood in my mouth. As this has occurred more often these past few weeks, I'm becoming a bit anxious'.

The task of a group of students is to explain these phenomena in terms of underlying processes. Explanations take the form of physical, biological or psycho-social mechanisms that may be underlying the phenomena concerned. (A more practical task can be formulated for the group, i.e. requiring them to ask themselves what they would do if they were the doctor for the person described. What kind of questions would they ask, what laboratory tests would they order, what physical examination would they perform and what treatment would they suggest? This task is secondary to that of explaining the symptoms, because understanding precedes rational action, both in education and in practice.)

While working on the problem, the study group uses a systematic procedure to analyse the problem, to formulate learning objectives and to collect additional information. This procedure consists of seven steps (Table 1).

(1) The first activity in relation to any problem should be clarification of terms and concepts not understood on first sight. Use may be made of group members' relevant knowledge. In some instances also a dictionary is of help, whereas in others the first step consists in reaching agreed opinion about the meaning to be attached to the various terms. In the latter case, therefore, the aim is consensus about interpretation rather than clarification of terms. If a group of students dealing with the 'oral blood loss' problem should be unfamiliar with a plumber's duties, the dictionary will inform them that he engages in the 'installation and maintenance of water-conduits and sewerage systems in and about the building'.

(2) The second step aims to produce an exact definition of the problem. The group as a whole has now to reach agreement about which interrelated phenomena should be explained. More often than not problems do not present difficulties in this respect. Occasionally, however, a problem is intentionally structured to tax students about the recognition of symptoms. Some problems consist of a series of secondary, independent problems; these must be identified as such before further completion is possible, i.e. the question to be answered in order to define the problem is: Which phenomena have to be explained?

(3) Analysis of the problem calls for careful perusal of the text to gain a clear impression of the situation described, which results in ideas and suppositions about the structure of the problem. These are either based on students' prior knowledge or are the result of rational thought. Hence, analysis of the problem substantially consists in recapitulation of group members' opinions, actual knowledge, and ideas about the underlying processes and mechanisms. The group does not confine itself to activation of prior knowledge ('I've read somewhere that...'), but also tries to formulate relevant hypotheses by sound reasoning ('Could it be that...?').

Most of the time a kind of free association-round is held, in which each individual is allowed to verbalize ideas freely before the ideas, knowledge and suppositions are scrutinized, accepted, complemented or modified. This procedure is often referred to as the 'brain-storming' technique. Application of analytical efforts of this kind to the oral blood loss problem may yield the following line of thought, illustrated by a verbatim transcript of an actual problem-analysis by a group of Dutch first-year medical students.

TABLE 1. Steps involved in problem-based learning

Step 1:	Clarify terms and concepts not readily comprehensible.
Step 2:	Define the problem.
Step 3:	Analyse the problem.
Step 4:	Draw a systematic inventory of the explanations inferred from step 3.
Step 5:	Formulate learning objectives.
Step 6:	Collect additional information outside the group.
Step 7:	Synthesize and test the newly acquired information.

'Could we have a case of lung cancer here? The site of origin of the oral blood need not be the lungs at all. Injury in the throat or in the mouth itself may have occurred. But how? Coughing subjects blood vessels to a pressure increase: people who cough vigorously often turn red in the face. Does that not point to a ruptured vessel? For that matter, why does one cough? The reason may be the presence of an irritant in the air passages, an inspired peanut, or phlegm. Coughing is a reflex mechanism for clearing the respiratory tract and expelling foreign bodies.

People suffering from tuberculosis sometimes cough up blood. The plumber has now had this for 2 weeks, the oral blood loss, I mean. I wonder if he has actually been coughing much longer. Perhaps he is a smoker. But why this blood? I can imagine that the sudden explosive expulsion of a stream of air results in such a high air pressure that something gets damaged. A tumor? It might well be the obstruction creating the coughing stimulus. Being a plumber, he frequently works in draughty rooms and spaces. He may also have caught a severe cold then, an inflammation of the mucous membrane in the respiratory system caused by a virus or something similar. In my opinion certain glands in the mucous membrane secrete an abnormal amount of mucus to protect the body against the virus. But what about the blood?

By the way, cancer of the lung is a growth of malignant cells, malignant lung tissue. It expands in the lungs, so that they can no longer function properly. Well, I am not sure about the exact process. Tuberculosis? That is a disease brought about by the tubercle bacillus. A type of inflammation of the lungs.'

(4) In the fourth step a systematic inventory is made of the various explanations of the problem. In the above analysis, several general descriptions of biological phenomena were advanced. The first one relates to the students' ideas about the origin of the coughing ('a reflex mechanism activated to clear the respiratory tract and expel obstructions'). The second covers the possible connection between coughing and a bleeding ('I can imagine that the sudden explosive expulsion of a stream of air results in such a high air pressure that something gets damaged'). The other descriptions refer to the many obstructions that may affect the air passages ('inflammation of the mucous membrane', 'cancer of the lungs', 'tuberculosis'). The systematic inventory might yield the scheme shown (Fig. 1).

An inventory such as this acts as a kind of

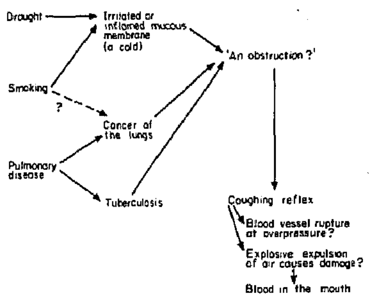

FIG. 1. Schematic presentation of the oral blood loss problem.

summary and structures the product of the problem-analysis.

The point is now reached when the assumed processes and mechanisms referred to in the analysis are to be studied more extensively. To what degree can the expressed knowledge and ideas be considered correct and complete? Study priorities have to be established because, as a rule, there is not enough time to pay adequate attention to all aspects involved.

(5) The fifth step, therefore, requires formulation of learning objectives. These are the answers to the questions evoked by the problem analysis phase, to gain a more profound knowledge of the processes forming the crux of the problem. In the example cited the following questions might arise:

What physiological mechanisms are involved in the coughing reflex?

In what way does draught affect the air passages?

How does bleeding result from coughing?

What causes mucous membranes to become inflamed and what does the membrane look like in this state?

What is the effect of smoking on the respiratory tract?

What is lung cancer?

What is tuberculosis?

The group selects the objectives on which it will concentrate its activities and, if necessary, agrees on a distribution of tasks. Finally it tries to find out which learning resources might supply the required answers.

(6) The sixth step consists of individual study. The group members individually collect information with respect to the learning objectives. The source explored may be literature, but other tools may also serve. For instance, audiovisual aids might be employed. Experts can be consulted about aspects of the problem not yet clarified.

(7) The process of problem-based learning is completed by synthesizing and testing the newly acquired information. The students inform one another about their individual findings, supplement this knowledge, and correct it where necessary. It is then established whether the group is now capable of giving more detailed descriptions of the fundamental processes, in the problem. Often new questions are proposed in the course of this exchange of information. In that case the group may decide to take up again the process of problem-based learning—now at a deeper level of understanding—starting with the fourth step. However, it may prove equally effective in that phase to exploit the newly acquired know-

ledge by tackling a different, though related, problem in order to find out whether the group can now perform the analytical and explanatory task in a faster and better way.

Discussion

When the conditions that facilitate human learning three principles were discussed, it was concluded that instructional methods should stimulate students by activating relevant prior knowledge, providing a learning setting as similar as possible to the setting in which the acquired knowledge is to be used (encoding specificity), and by giving students opportunities to elaborate on their knowledge. Does problem-based learning meet these conditions?

To meet the requirement that problem-based learning should lead to the activation of relevant prior knowledge, attention must be paid to the characteristics of the problems being used. Written problems will activate relevant prior knowledge only if they have the following features (Willems, 1981):
(1) they should consist of a neutral description of an event or a set of phenomena that are in need of explanation in terms of underlying processes, principles or mechanisms;
(2) they actually do have to lead to problem-solving activity. If students are asked to study 'the heat-regulating mechanism of the human body', this task will not lead to activities such as described in the preceding section. But the following problem will do so: 'You have been playing a game of tennis. You've a red face and are wet all over your body. How can these phenomena be explained?';
(3) problems have to be formulated as concretely as possible;
(4) problems should have a degree of complexity adapted to students' prior knowledge. If a problem is not complex enough, it will not be recognized as a problem. If it is too complex, students will think that it is no use trying to solve it.

The second condition that facilitates learning (encoding specificity) is met by the problem-based learning approach insofar as problems are used that have a close resemblance to problems that students will come across in later professional life. Barrows & Tamblyn (1980) and Neame (1981) further specify this condition by proposing that problems should be chosen:
(5) that have the greatest frequency in the usual practical setting;
(6) that represent life-threatening or urgent situations;
(7) that have a potentially serious outcome, in terms or morbidity or mortality, in which intervention—preventive or therapeutic—can make a significant difference in prognosis;
(8) that are most often poorly handled by doctors in the community.

The third facilitating condition, giving students opportunities to elaborate on their knowledge, is augmented during group discussion, when students provide each other with opportunities for amplification and change of existing knowledge structures. When students try to explain the blood loss problem by hypothesizing possible processes responsible for the phenomena observed, they are not merely reproducing knowledge acquired at some point in the past. They are using this knowledge as 'stuff for thinking'. In doing so, previously unrelated concepts become connected in memory, newly produced insights change the structure of their cognition, and information supplied by peers is added. The same applies to the last step of the problem-based learning procedure where newly acquired information is exchanged, critically discussed and eventually applied. These are the activities that can be viewed as elaboration processes.

So far only the *potential* qualities of the problem-based learning approach as an instructional method have been discussed. The question is whether there is any *empirical* evidence regarding the effectiveness of the approach. One can ask whether problem-based learning really promotes the acquisition of knowledge that is applicable. Research on this topic is in progress at the Department of Educational Development and Research at Maastricht. In one investigation, Boshuizen & Claessen (1981) compared groups of students at Maastricht (where the problem-based learning approach has been adopted) with students from a traditional medical faculty in a number of problem-solving tasks. Each student was given case histories of two patients suffering from pancreatitis and prostatitis. Each of these case histories was presented on a series of cards, each card containing a piece of information with respect to the patient. The student had to read these cards and comment on the information. After processing the case history in this way the subject was asked among other things to write down a differential diagnosis, to rate the information on the cards in terms of its importance, and to recall the information. Some small but reliable differences were found in favour of the Maastricht medical students. This suggests that a problem-based curriculum may provide better opportunities for learning to solve medical problems. In another investigation the present writer tested the problem-based learning hypothesis more directly (Schmidt, 1982). Small groups of students analysed a written problem on osmosis. Subsequently, they studied a text containing new information relevant to this topic. As compared with control subjects that only studied the text, the experimental subjects were better in recognizing the information from the text and in using it in order to solve small problems.

The conclusion is that the available theoretical views and empirical evidence suggest that problem-based learning, in the least, be considered a useful addition to conventional instructional methods, and can perhaps be used as an alternative approach.

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