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The Psychological Basis of Problem-based Learning: A Review of the Evidence

Abstract—Several potential advantages for students' learning are claimed for problem-based learning (PBL). Students in PBL curricula may be more highly motivated; they may be better problem solvers and self-directed learners; they may be better able to learn and recall information; and they may be better able to integrate basic science knowledge into the solutions of clinical problems. Although some of these claims find theoretical support from the literature on the psychology of learning, to date there has been no review of the experimental evidence supporting the possible differences in students' learning that can be attributed to PBL. In this review article, the authors examine each claim critically in light of that evidence. They conclude that (1) there is no evidence that PBL curricula result in any improvement in general, content-free problem-solving skills; (2) learning in a PBL format may initially reduce levels of learning but may foster, over periods up to several years, increased retention of knowledge; (3) some preliminary evidence suggests that PBL curricula may enhance both transfer of concepts to new problems and integration of basic science concepts into clinical problems; (4) PBL enhances intrinsic interest in the subject matter; and (5) PBL appears to enhance self-directed learning skills, and this enhancement may be maintained. *Acad. Med.* 67(1992):557–565.

From its beginning at McMaster University in the mid-1960s, problem-based learning (PBL) has caused a small revolution in the medical education community. About 60 medical schools worldwide have adopted the method in whole or in part, and others are in the process of doing so. Such august bodies as the Association of American Medical Colleges and the World Federation of Medical Education have wholeheartedly endorsed the approach.[1,2] It is ironic that a professional community that prides itself on adherence to the scientific method has swung so strongly toward this innovation, despite considerable evidence that the differences in favor of PBL, at least at the level of curriculum comparisons, are small indeed.[3]

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The purposes of this paper are to examine the psychological basis for PBL using one or more theoretical perspectives (primarily from cognitive psychology) and to review some recent studies relevant to these perspectives. It is not our intent to examine the diffusion of this particular innovation or to review the evidence of the overall benefits or deficiencies of PBL. Consequently, we avoid commenting on holistic studies comparing the performances of students or graduates from one curriculum with those from another on batteries of measures of competence; instead, we present evidence derived, by and large, from experimental studies directed at testing various hypotheses regarding learning. From this review, we attempt a synthesis of the advantages and disadvantages of PBL in terms of psychological constructs and present recommendations for critical research issues.

Goals of PBL

The PBL approach can be characterized as follows: A collection of carefully constructed problems is presented to small groups of students. The problems usually consist of descriptions of sets of observable phenomena or events that need explanation. In medical education, they usually take the form of a description of a patient presenting a complaint supplemented with some critical signs and symptoms. The task of the student group is to discuss these problems and produce tentative explanations for the phenomena, describing each in terms of some underlying process, principle, or mechanism. Here is an example of a PBL problem:

> A 55-year-old woman lies crawling on the floor in obvious pain. The pain emerges in waves and extends from the right lumbar region to the right side of the groin and to the front of the right leg.

Given this text, students are required to find explanations for the source of the pain described, its physiological processes, and the mechanisms through which it extends from a certain area to other areas of the body. Essential to the method is that students' prior knowledge of the problem is, in itself, insufficient for them to understand it in depth. During initial discussion, dilemmas will arise and questions will come up that can be used as learning goals for subsequent individual self-directed learning. In addition, students may attempt *to solve* the problem, suggesting ways to diagnose and manage the particular case. While discussing a problem, the group is guided by a tutor, usually a member of the faculty. A problem-based course tends to be thematically organized rather than discipline-based and is often prepared by a small team of teachers who have backgrounds in different disciplines. The core instructional materials are, of course, the problem descriptions and a well-stocked library. However, references, audiovisual aids, and occasional lectures are included as learning resources relevant to the comprehension of the problems.[4]

According to Barrows,[5,6] a primary goal of PBL is to foster clinical reasoning or problem-solving skills in students. He assumes that through continuous exposure to real-life problems with solution strategies modelled by their tutor, students will acquire the craft of evaluating a patient's problem, deciding what's wrong, and making decisions about appropriate actions to treat or manage the problem.

A second objective is to enhance acquisition, retention, and use of knowledge. It is suggested that learning new knowledge in the context of problems may foster its retrievability and use when needed for the solution of similar problems. Schmidt and colleagues[4] assume that the activation of prior knowledge, taking place while a problem is discussed initially, may have a stage-setting function for new knowledge that facilitates the student's processing of it.

Problem-based learning may also narrow the gap between the basic and clinical sciences, which are taught in circumstances separated by both time and place in the conventional curriculum. Students from a PBL curriculum may be better able to marshall and integrate basic science into the solution of a clinical problem, since they have learned many of the basic science concepts while solving simulated clinical problems.

Another frequently mentioned objective of problem-based learning is to enhance "self-directed learning" skills. Barrows states that students should be

> able to extend or improve on their knowledge base to keep contemporary in their eventual field of medicine and to provide appropriate care for the new or unique problems they may face in their work. This is self-directed learning. There are several components in this skill. . . . [One] component is the proper formulation of learning needs to determine the best resources for satisfying that need in terms of efficiency and resource availability. Another component is the proper use of available resources. Again, it is my opinion that most doctors do not know how to use a library effectively or even how to use experts or consultants effectively. Self-learning is not finished until the knowledge and skills that have been newly acquired through self-study are properly encoded in memory for subsequent recall and use. The teaching in most medical schools does not emphasize these skills.[5]

Students' intrinsic interest in subject matter, with a consequent impact on the motivation to learn, may also be enhanced by PBL. Bruner,[7] for instance, suggests that when students work on problems perceived as meaningful to them, they show interest in issues relevant to those problems that goes beyond merely studying to pass an examination. Hunt[8] explains this phenomenon by assuming that people, when confronted with a situation not easily understood, seek information in order to fill the gaps. The confrontation with meaningful but poorly understood problems would drive the learning. Hunt considers this intrinsic need of the organism to reduce incongruence to be an inherent feature of the cognitive process.

In the next sections we discuss the evidence presently available regarding the extent to which PBL indeed promotes all these objectives when compared with more conventional approaches.

PBL for the Acquisition of Problem-solving Skills?

One premise of problem-based learning was that it would be more successful at teaching "problem-solving skills."[5] A related concept is that of "inquiry skills"[9]—general skills that can be applied to gather, interpret, and integrate data from any clinical problem.

Certainly the notion of the teaching and assessment of problem-solving skills predated the McMaster innovation[10] and much effort was expended in the 1960s to teach,[11] evaluate, and simulate[12] general problem solving. However, in light of the subsequent research, in medicine[13] and many other domains,[14] the notion of a general problem-solving skill that can be taught and learned is not a particularly useful construct. Repeatedly, evaluation studies have demonstrated that the correlation of scores across problems, regardless of the particular simulation method or scoring algorithm, is about 0.1 to 0.3; this phenomenon now is labelled *content specificity*.[15] In addition, it has been difficult to demonstrate any change in measures of the problem-solving process from the first year of medical school to clinical practice.[16] Similar comments apply to inquiry skills,[17] which also show little evidence of generalizability or improvement with education.

But if these results are taken literally, the implication is that there are no general characteristics to problem solving. This is clearly too extreme—there may be some kinds of discipline-specific strategies that can be generalized for some classes of problems,[13] but these have yet to be identified and measured. Certainly, to date there is no evidence indicating that one curriculum or another, problem-based or otherwise, is able to enhance students' problem-solving skills independent of their acquisition of knowledge.

If there is little support for the idea of acquiring general problem-solving skills, what role is there for problem-based learning? Based on fundamental research in cognitive psychology, at least three roles (to be discussed) can be envisioned: (1) The acquisition of factual knowledge *in the context in* which it will subsequently be used, (2) the mastery of general principles or concepts in such a manner that they can be transferred to solve new, similar problems, and (3) the acquisition of prior examples that can be used for problem solutions on the basis of similarity or pattern recognition. (To some extent these three perspectives parallel three representations of clinical reasoning identified in a recent theoretical paper.[18]) The scientific bases of these proposed rules of PBL emerge from very different traditions in cognitive psychology: the first from research on memory, the second from research on problem solving and "case-based" reasoning, and the last from research on concept formation and categorization.

The Acquisition of Factual Knowledge

There is an enormous literature on factors affecting memory and recall. One conclusion is clear: the implicit theory of many educators, that the mind is a leaky vessel to be filled with facts at a high enough rate that they don't all flow out, finds little support in this literature. The computer metaphor of a short-term, working memory, with easy access but limited size, and a long-term memory, of near-infinite size with effortful storage and retrieval, has been useful in many areas of cognitive science, but this too has proven to provide only a limited account of the working of human memory. One need only imagine programming a computer to recognize a companion on the street or to recall the lyrics of a musical tune last heard many years earlier to recognize that, despite their architectural advantage in reliability and speed, there are many areas where computers are no match for human memory. No brief summary can do justice to the field of the psychology of memory; instead we focus narrowly on three aspects of memory relevant to the assessment of the effects of problem-based learning.

Activation of prior knowledge facilitates the subsequent processing of new information.[19] A maxim of cognitive psychology is that prior knowledge about a subject determines to a large extent what people can learn about that subject. Spilich and colleagues,[20] for instance, found that the persons studied who were very knowledgable about baseball remembered more information and more relevant information from a report of a baseball game than did the individuals with relatively little knowledge. In the domain of chess, grand masters were able to recall positions of pieces on the board more accurately than were players with less knowledge and experience.[21] Having prior knowledge is a necessary but not sufficient condition for learning to take place. In a series of classic experiments, Bransford and associates[18,22] demonstrated that the comprehension and hence the recall of new information are extremely poor when subjects fail to activate relevant knowledge. The instructional context must be such that activation can take place. Small-group discussion of a problem is one of the methods to activate relevant prior knowledge.

Elaboration of knowledge at the time of learning enhances subsequent retrieval.[23] The memory of subject matter and the ability to use the knowledge is enhanced when students have the opportunity to elaborate on the knowledge at the time of learning.[24] Elaboration can take several forms—discussion, note-taking, answering questions, or using the knowledge to understand a problem.

Matching context facilitates recall. One factor that influences retrieval of knowledge is the provision of a context similar to the context at the time of learning.[25] The difficulties in remembering the name of one's colleague when encountered in the grocery store and in recalling the name of one's neighbor when seen at the hospital are vivid illustrations of the influence of context. In one classic study with Royal Navy divers, word lists learned on land were recalled better on land, those learned underwater were recalled better underwater.[25] It is important to note that the context includes all features of the environment at the time of learning, not simply those judged by some external criterion to be, in some way, important or relevant to the material learned. Thus, when material about a patient's problem is recalled, objectively irrelevant features of the patient, such as hair or clothing, will be recalled in addition to clinically important features. Hassebrock,[26] for example, asked physicians to recall their last case of ventricular septal defect; this had occurred an average of 5.4 years earlier. The physicians remembered more details of the activities they had performed at the time and the patient and his or her family than of the medical features of the problem.

There are several reasons why PBL appears to provide an appropriate context for learning. Since all the relevant concepts, from anatomy to epidemiology, are learned in the context of a clinical problem, usually presented on paper in a small-group setting, they should be more available and better integrated when a similar problem is encountered in a clinical setting. In this setting there is ample opportunity for elaboration of concepts as students challenge each other. Last, the usual PBL approach of first working through a problem without consulting resources is a mechanism to activate prior knowledge. If these theoretical advantages have impact, there should be a demonstration of enhanced recall after some elapsed time when students are in clinical settings.

There have been several direct tests of the effect of PBL on recall. Martensen and colleagues[27] demonstrated that students in a problem-based course showed no difference in short-term recall but a significant advantage in long-term recall amounting to 60% higher scores for the problem-based instruction after a period of two to four and a half years. A partial replication of this study was performed by Eisenstaedt,[28] who showed that the immediate knowledge of students in a problem-based course was lower, but that their forgetting curve over a period of two years was essentially flat, so that after this period the difference between the two groups had disappeared. Tans and colleagues[29] compared the performances of physiotherapy students randomly assigned to either a problem-based or a lecture-based version of a course in muscle physiology. The students in the problem-based course performed significantly poorer on an immediate multiple-choice test, although this was largely because the PBL students had pursued and studied relevant topics that were not expected or assessed by the teacher. A free-recall test of core knowledge taken after six months showed the reverse: the students under the problem-based condition recalled up to five times more concepts than did the control group. These findings are consistent in indicating that PBL indeed induces students to retain knowledge much longer than it is retained by students taught under conventional teaching conditions. They also show that students' initial learning may be poorer —possibly because it is difficult to test exactly what students have learned under a problem-based regimen, possibly because students under this condition learn less initially— but that they process the information learned more extensively.

Support for such a processing explanation comes from a series of studies by Schmidt and associates.[30–32] They presented each of several small groups of students with a problem that was either relevant or irrelevant to a text to be studied subsequently. Each group discussed its problem for a specified period of time and later read the text, which provided new information. The groups that had discussed the relevant problem recalled significantly more information from the text. The investigators explain this finding by suggesting that problem discussion stimulates the activation and elaboration of prior knowledge that, in turn, facilitates the processing, comprehension, and recall of the text. Since the groups discussing the irrelevant problem activated knowledge not relevant to the subsequent text, they did not profit from the instructional manipulation. Support for this explanation was found in an experiment in which individuals were required to discuss either a problem to be explained with knowledge they had acquired several years before or a neutral problem.[28] When required to recall the knowledge acquired before, those who discussed the relevant problem recalled much more from their previously acquired knowledge than did the others. This suggests that problem-discussion indeed activates prior knowledge, both recent and distant, which is elaborated upon and subsequently used for the comprehension of new information.

Transfer of Principles and Concepts

We have already indicated the fallacy in the notion that general fundamental cognitive skills can be acquired from a course in Latin, logic, or lateral thinking and then used to solve broad classes of problems in other fields. But we still teach the basic principles or concepts of biomedical science, often with examples of their application, in the preclinical years with the implied hope that these important concepts will be available and used in the solution of patients' problems. The issue is one of *transfer*, the extent that a concept or principle learned in one context can be transferred or applied to a problem that, while different in initial appearance, requires the same principles for resolution. No one expects broad transfer any longer, but research over the past two decades appears to indicate that transfer to analogous problems is more narrow than even the worst pessimist might have feared.[33–35] In a sense this is the opposite of the finding discussed in the previous section. Matching the context or the surface similarity of two problems will serve as a powerful reminder, whether or not the two problems are analogous. Conversely, a number of studies of problem solving have shown that any change in the surface features of a problem impedes transfer so that the problem solver does not recognize the similarity of the underlying concept and the analogy is not utilized. Without specific hints, usually less than half the individuals in an experiment recognize the similarity between a new problem situation and one that they have just read and recalled.

Some elaboration may be useful. One of the classic problems[36] used in experiments in this tradition involves focusing X-rays on a tumor from several directions in order to get a sufficiently high radiation dose to the tumor without damaging the surrounding tissue. (This kind of research began in 1945, long before modern radiotherapy techniques had been developed.) In a typical experiment, individuals read an analogical problem in which a general captures a fort by sending small groups of soldiers along a number of roads to attack at the same time. If the readers are told that this problem is analogous, transfer is successful; however, even if the experimenter explains the underlying principle and draws diagrams, no transfer occurs unless the analogy is explicitly pointed out. Using two to three analogous reading problems appears to help transfer, but only if the readers make specific comparisons among the representations.[37] But in one study,[37] even after an hour of such comparisons, only about half the subjects were able to solve the new problem.

However, until recently, the experiments have not given adequate cognizance to the idea that the task itself is part of the context; that is, in order for transfer to occur, people must be processing the information similarly to the way they will process it when they approach the new problem. Virtually all of the preceding experiments had subjects learn the examples for meaning (for instance, by being asked to recall the text), but did not ask the subjects to solve the problems in the examples. A recent series of experiments by Needham and Begg[38] contrasted a group who were asked to read and remember a problem and then had the solution explained with another group who were engaged in solving the problem, who then were given the solution also. Then both groups were given sets of test problems that illustrated the same problem in very different contexts from those in which it had been presented originally.

Most educators would view the first approach as perfectly sound educational practice; teachers often use instructional time to work through the solution of problems and then assign additional problems for students to practice the solutions. Notice also that processing to remember is not "rote"; memorization is most successful when the test is processed meaningfully.

The results showed that those who were asked to solve the prototype problem and received feedback about the problem typically transferred the concept to a new problem nearly 90% of the time, versus about 60% for those who were simply asked to memorize the problem. However, another experiment showed that simply engaging in problem-solving activity is not sufficient. When no feedback about the correct solution was provided, the advantage of the problem-solving condition disappeared. What was also interesting in comparing this experiment with others was that feedback about the solution conferred no advantage at all to the "remember" group, whose performance on the test problem was maintained at about 60%. A final experiment in the series demonstrated a double dissociation: those in the "remember" group actually did remember more than those in the problem-solving group, yet solved the new problem less frequently. Therefore, the low transfer of those in the "remember" condition was not a result of superficial or cursory processing of the initial problem.

The dramatic contrast between the Needham and Begg results and previous work in this area has important implications for PBL. Learning concepts while trying to solve a clinical problem is precisely analogous to the problem-solving condition of the Needham–Begg experiments. By contrast, the tradition in education of teaching a concept, then having students try to apply it to a problem "at the end of the chapter" is analogous to the memory condition. The studies also reveal answers to some of the common concerns about PBL. In these studies, nothing in the problem identified the nature of the underlying concept, and thus the students were forced to reason and reflect in the course of problem solution. By contrast, the students in the earlier studies and those who were in the "remember" condition failed to transfer because the solution was provided, not because they were inattentive. Thus, it seems that any "advance organizer" that detracts from the problem-solving process, such as the common expedient of identifying a problem in advance (e.g., "a problem of electrolyte imbalance") may result in a serious decrement in transfer. A second significant finding from these experiments is that problem solving without feedback is insufficient for success. Students without feedback typically succeeded on the first problem less that 10% of the time, and one experiment demonstrated that in the absence of feedback, the advantage of the problem-solving condition disappeared.

Thus, there appear to be two prerequisites for successful transfer from a learning session around a problem: (1) the problem must be approached in a problem-solving modality without much foreknowledge of the domain of the solution or the underlying principle; and (2) the problem solver must receive corrective feedback about the solution immediately upon completion.

In light of the recency of these findings, and the somewhat counterintuitive result that being able to recall a solution is *inversely* related to being able to apply it to new situations, it is not surprising that there is at present little evidence that the phenomenon is borne out in problem-based curricula. Still, if the results are eventually demonstrated in medical education, there are important implications of these basic research findings for problem-based curricula. First, the study of concepts while attempting to solve a problem appears to be an optimal strategy for spontaneous transfer of the concept to new problems. This is *not* the same as reading the solution to a problem or learning a concept first and then attempting to apply it to a problem later. However, it is not sufficient to engage in the act of solving the problem; students must receive corrective feedback during the course of attempting to solve the problem.

Because students in a PBL curriculum learn basic science concepts in the context of a clinical problem, it would appear reasonable that they should be better able to integrate these concepts in the solution of other clinical problems. Patel and colleagues[39] asked students from a conventional and a problem-based curriculum to solve a clinical problem and then integrate three passages of relevant basic science knowledge into their explanations of the problem. The students from the problem-based curriculum advanced many more causal explanations than did the students from the conventional curriculum. The students from the problem-based curriculum were able to integrate basic science and clinical knowledge at all levels; the students from the conventional curriculum in the preclinical years did not adequately deal with the clinical aspects of the problem, and those in the clinical years were no longer able to deal with the basic science information. Nevertheless, although the students from the problem-based curriculum did hypothesize a large number of causal explanations, many were incorrect. Whether this was a result of specific characteristics of the curriculum studied, which makes extensive use of non-expert tutors and is relatively unstructured, remains to be seen.

In another study of the effects of curriculum type on knowledge integration, Boshuizen and Schmidt[40] compared the performances of preclinical students from two medical schools, one with a problem-based curriculum and one with a conventional curriculum. The students were asked to explain how a specific metabolic deficiency and a specific disease could be related, e.g., "How does a genetic deficiency of pyrovate kinase lead to hemolytic anemia?" In answering this question, knowledge about biochemistry and about internal medicine must be applied and integrated. In addition to these student groups, two classes of experts were incorporated in the study: biochemists and internists.

The students from the problem-based curriculum and the biochemists appeared to take an analytical approach to the problem by first exploring its biochemical aspects and later linking them to clinical aspects. The students from the conventional curriculum and the internists tended toward a more memory-based approach. They searched their memories in order to find a direct answer to the question. This latter strategy, however, resulted in significantly less accurate answers and more failures by the students from the conventional program. These results suggest that students in a problem-based curriculum integrate their knowledge better than do students in a traditional curriculum, which means that the former students can solve problems more effectively.

Taken together, these studies show that students in a problem-based curriculum tend to do better in causal explanation of the pathophysiologic processes underlying disease. However, it is not immediately apparent why the PBL-trained students in the Patel and colleagues study were making more mistakes than were the students from the conventional school, whereas Boshuizen and Schmidt found the reverse. One possible explanation may lie in the specific curriculum implementations at the two PBL schools involved: McMaster is relatively less structured than is the University of Limburg, which may result in less corrective feedback and the persistence of conceptual errors.

Prior Examples and Pattern Recognition

There is more than one way to solve a problem. Perhaps the hardest, most time-consuming, and most error-prone is to attempt to reason out a solution from basic principles. Certainly the easiest, most efficient, and least error-prone is to recognize that you have solved it before, and then recall the solution. In fact, many judgment decisions we make in everyday life (Is it a dog or a cat? Is that my wife? Why doesn't the lawn mower work—again?) are made on the basis of similarity, almost without conscious awareness. In the medical domain, this approach is frequently called "pattern recognition," or more particularly, "just pattern recognition," presumably because of its apparent ease, not its effectiveness and efficiency.

Research into this activity has led to a theory of concept formation—the *instance* theory—that supposes that for everyday classes of concepts, individuals have available in their memories many individual instances, and that individuals make many categorical and diagnostic decisions on the basis of the similarity of a current instance to prior ones. A number of experimental studies using artificial materials have demonstrated the memorability and utility of prior instances.[41] It is also important to note that many of those studies have demonstrated that individuals indeed do make decisions on the basis of the similarity of the present situation to prior instances without being aware of doing so. Under these circumstances, it is likely that people will underestimate the effect of similarity and will ascribe their efforts to "automatic response," "intuition," or "unconscious problem-solving."

Some evidence of the effect of this kind of decision making in medicine is derived from studies in dermatology in which prior experience was manipulated directly.[42] One study used an elaborate experimental design and a two-stage intervention in which the persons studied learned a series of examples, displayed on slides, and then were tested. The study showed that seeing the previous example improved diagnostic accuracy by 10–15% when the individuals saw similar-appearing slides, but there was no advantage when they saw the other slides in the same diagnostic category. Thus, the effect of prior examples was based on similarity rather than on any priming of the individual regarding the diagnostic category. A second study then varied the instructions to emphasize the early nonanalytical (i.e., perceptual) phase ("Give us your first impression") and a later analytical phase ("Before you decide, argue for these alternatives). Most slides were correctly identified in the first phase, suggesting the importance of rapid perceptual processing. The effect of the second phase was to increase the correct reporting of visually dissimilar slides, but not at the cost of reduced accuracy with similar slides.

A related study[43] was conducted on medical students and graduate students using a similar learn–test strategy. This study showed that the effect of a similar-appearing example from the same or an alternative diagnostic category during the learning phase was sufficient to change correct diagnosis from 42% to 89% over intervening periods as long as two weeks.

There is not yet evidence of the effect of PBL on instance-based reasoning. However, it is a plausible argument that one effect of problem-based curricula is to amass the individual instances essential to the competent diagnostician. We are now at the point where tests of pattern recognition have been developed[44] and might be used in large-scale trials of PBL. The ideal test would be the demonstration that students in a problem-based curriculum are more successful in diagnosing such problems using minimal information, simply because the additional exposure to problems leads to an accumulation of prior instances that are available for the solution of new problems.

Problem-based Learning and Intrinsic Interest

Learning in educational institutions is, to a large extent, driven by external awards. Students acquire new knowledge, not as a goal in itself, but in order to pass an examination, to get a high grade, or to eventually earn a high salary. Consequently, the nature of the subject matter studied and the depth of learning are determined not so much by interest or perceived importance as by the nature of the reward. That, in itself, would present no particular problem, provided the right activities are rewarded. However, research has demonstrated that not only does reward steer the learning, but in fact it may reduce intrinsic interest and make the subject matter studied less interesting. Lepper and Greene[45] have shown that individuals who were rewarded actually spent less time performing learning tasks and considered them less attractive. The authors concluded that extrinsic reward undermines intrinsic motivation by "turning play into work."

It may come as no surprise that much research in education has been aiming towards making learning more intrinsically interesting. Johnson and Johnson,[46] for instance, required children to discuss the consequences of coal mine stripping. Prior to the discussion, half of them received information stressing the environmental hazards, while the others received texts emphasizing the economic advantages of coal stripping. They were asked to defend the position allotted, listen carefully to the other position's arguments, and try to refute them. Compared with other children in the control group, who only read the material or discussed it without taking a stance, the children involved in the "controversy" discussion performed better on a subsequent test. In addition, they displayed more interest in the subject and spent more time seeking additional information about it in the school's library.

The effect of problem-based discussion on intrinsic interest has been studied mainly at the University of Limburg in the Netherlands.[47,48] De Volder and colleagues, for instance, demonstrated that students who discussed a problem relevant to the topic of osmosis displayed more attraction to the subject, were more interested in studying the relevant literature, and were more willing to attend a lecture on osmosis than were the students not involved in such discussion. This finding seems to indicate that PBL involves students more extensively in the topic at hand. However, no relation could be found between the students' responses and their subsequent performances on a test, suggesting that intrinsic interest does not play an important role in the causal chain between treatment of a topic and performance related to that topic. It seems that more research is necessary to elucidate the role of intrinsic interest in PBL.

PBL, Self-directed Learning, and Lifelong Learning

There is an extensive literature on the psychology on aging and expertise that is paralleled by a number of studies in medicine examining the relationship between a physician's age or the length of time since graduation and his or her clinical competence. The studies in psychology indicate that aging is accompanied by a decline in some mental operations such as coding and retrieval; however, this is not apparent in skilled performance because there are compensatory mechanisms, such as more efficient search strategies.[49] In medicine, a number of studies have showed a negative relationship between the physician's age or time since graduation and his or her knowledge[50] or clinical performance.[51] The question remains whether this decline is due to forgetting previously learned information or due to an inability to learn new information. Day and coworkers[52] studied physicians' performances on a recertification examination, and categorized all questions as "old," "new," or "changing" knowledge. It was clear that the decline in performance over time after graduation was due to a relative inability to acquire new or changing knowledge and was not a result of forgetting previously learned knowledge.

That being the case, the emphasis in problem-based curricula on self-directed learning skills may lead to practitioners who are better able to keep up with the literature. However, at a minimum, it must be shown that (1) students in a problem-based curriculum actually acquire more self-directed learning skills than do students in a conventional curriculum; and (2) this difference is sustained beyond the duration of the curriculum. There is some evidence to support both these hypotheses.

Blumberg and Michael[53] used a variety of measures, including library circulation data, to show that students in a problem-based track borrowed more material during the course than did students from the conventional curriculum (67 books/student/year versus 43) and that this difference was amplified in the clerkship (40 for students from the problem-based curriculum versus 11 for those on the conventional track). Shin, Haynes, and Johnson[54] have shown a higher score on a written test on hypertension for graduates of a problem-based program ten years after graduation; however, these data were not corrected for possible baseline differences in knowledge or for the differential retention of knowledge, as described earlier.

Conclusions

This review has shown some interesting differences between PBL and conventional curriculum strategies. It is evident that future studies are likely to maintain earlier studies' findings that there were small or negative differences between the overall knowledge or competence of students trained by PBL and by conventional curricula. However, there are substantial differences, related to the retention of knowledge and learning skills, that may be attributable to PBL. There is also a strong theoretical basis for the idea that PBL students may be better able to transfer concepts to new problems, and there is some preliminary evidence to this effect.

Equally important, the review points to some of the essential components of the PBL curriculum. In mastering facts and concepts, it appears important that students learn and acquire the concepts while puzzling through the problem, rather than in rote fashion prior to approaching the problem. It is also important that students receive immediate corrective feedback regarding incorrect concepts, either from expert tutors or by other means.

These observations suggest alternative approaches to the implementation of PBL. From a cognitive perspective, to achieve the goal of acquiring facts and concepts, it may be equally efficient to have students approach written problems individually or in small groups without a tutor, and then use faculty teachers for synthesis and explanation of the problems' solutions.

The review does indicate the paucity of critical research evidence available to address some, if not all, of these questions. The impact of PBL on students' retention of knowledge has been replicated several times; however, it is not clear why PBL students initially performed at lower levels on knowledge tests in some studies, while in other studies they performed at the same levels as did the conventional-curriculum students. The issue of the effect of curriculum on "problem-solving skills" may well be viewed as a moot point, since the very existence of problem-solving skills can be challenged. Clearly, any further research in this area must await better measures. The evidence of transfer in a PBL-like setting, indicated in the Needham–Begg studies, is dramatic and serves as a counterpoint to the depressing finding of minimal transfer derived from the weight of evidence to date. But that finding can be viewed only as a hypothesis about the potential impact of PBL, not a conclusion. By contrast, it is evident that PBL does have a large and potentially long-lasting impact on self-directed learning skills. Finally, the role of PBL in students' motivation appears fairly conclusive, both from the experimental work reviewed here and from the universal finding concerning graduates of PBL schools: that they find the learning environment more stimulating and humane than do graduates of conventional schools.

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