Review Articles

Problem-based learning

Challenges, barriers and outcome issues

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ABSTRACT

Although many recent studies have discussed specific issues related to problem-based learning in medical education, a comprehensive review of the literature on the consequences of its use and the outcomes of curriculum based on problem-based learning have not been accurately looked at. Furthermore, there is no available review that critically evaluates challenges and barriers to the implementation of problem-based learning curriculum in medical schools. The purpose of this part is to highlight the major challenges and barriers reported during curriculum preparation and implementation and to critically evaluate the consequences of problem-based learning introduction and its educational outcomes.

Keywords: Problem-based learning, resistance to change, medical education, new curriculum, challenges and barriers, integration, problem-based learning tutors, cognitive skills, basic and clinical sciences.

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Without major changes in the social context of medical practice, efforts to improve performance through curriculum reform will be futile.[1] A change to a problem-based learning (PBL) curriculum may be viewed with strong institutional constrains and even antipathy. The literature reviews mention a host of reactions to PBL. For example, doubts about claiming educational benefits of PBL, anxiety that the outcomes of PBL will not be very tangible, a disruption of habitual and comfortable patterns of work, as well as emotionally charged reactions and general fear of change.[2,3] Emotionally charged reactions, however, are not the only source of resistance to problem-based learning. It is important to guard against one-factor explanations. Other contributing factors should be considered.

Personal factors. Personal factors can influence an individual's attitude to any kind of change. Examples of these factors may include interest in, beliefs and attitudes towards education; approaches to learning and views of teaching; educational and academic background; and personal ambitions and career prospects. The openness to change of staff members in a department can vary dramatically and staff wishing to lead educational changes must be aware of the potential threats to such change and those factors which influence it, as outlined by Fullan.[4] Individuals who are very well established in their habits can find it difficult to consider or adapt to change, particularly if they feel elements of coercion operating. Even when the decision made to make a major shift in education is free of coercion and based on responses to positive influences, there remains uncertainty and potential stress associated with the unknown.[5]

Organizational issues. Any of these personal factors may interact with the particular characteristics of the institution in which an individual works. Universities, for example, differ in their organization,

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Table 1 - Application of PBL in professional sciences: Challenges/barriers experiences during implementation.

Sciences	Location	Type of the course	Challenges reported	Study type	Reference
Architecture	University of Newcastle, Australia	Integrated PBL	- Difficulties in integration -Difficulties in creating problems. - Polictical and professional challenges	Qualitative	Ostwald and Chen (1995)[8] Ostwald (1994, 1994)[9,10]
Mechanical Engineering	Imperial College of Science and Technology, UK	Non-integrated PBL	- Time consuming - Required changes in assessment	Qualitative	Cawley (1989)[14]
Nursing	University of Western Sydney	Integrated PBL	- Substantial change in management and organisational structure	Qualitative	Ryan and Little (1991)[7]
Optometry	Queensland University of Technology, Australia	Non-integrated PBL	- Time consuming - Student asked for more feedback - Disagreement within some groups	Qualitative	Lovie-Kitchin (1991)[15]
Social Work	University of New South Wales, Australia	Non-integrated PBL	- Resource intensive - Time consuming	Qualitative	Heycox and Bolzan (1991)[13]
Physiotherapy	University of McMaster, Canada	Integrated PBL	- A number of stressors were unique to adapting to PBL	Qualitative	Soloman and Finch (1998)[66]
Occupational Therapy	Brunel University College, UK	Non-integrated PBL	- Students were less clear about the goals/ objectives of curriculum.	Qualitative	Sadlo (1997)[61]
Veterinary Science	University of Queensland	Subject-based PBL	- Extra-time required from students compared to traditional lecture-based subjects.	Qualitative	Rand and Baglioni (1997)[67]

operation and ethos. Differences are multiplied across national boundaries. There are also major differences across cultures and political systems. The nature of the enterprise, the distribution of power and influence, the degree of external political control and the outlooks of the professionals involved will all interact to limit the styles and types and the outlooks of the professionals involved will all interact to limit the styles and types of change that are possible. The change is seldom a simple logical process and is not necessarily a smooth linear process.[2,6] Several studies have raised the issue of organizational resistance to the introduction of problem-based learning and the need for substantial change in the management system and organizational structure of their organization.[7-11]

Educational views. Nickles recounts the decline of the notion of a "logic of discovery" by the mid-19th century and the separation of discovery from justification.[11] This separation was significantly reinforced during this century by the distinction between "the context of discovery" and "the context of justification" made by Reichenbach in 1903. It seems that education has inherited the separation view and this has been reflected in beliefs about education. Nickles criticizes the separation of discovery from justification, arguing that the process of discovery and justification are closely linked.[11] PBL is consistent with Nickles' criticism of the rigid separation of discovery from justification. The implication of Nickles' argument on education is clear. Students will be ill served. They are given only the products of enquiry without learning how to

actually pursue enquiry. Solving problems is a process of discovery that is much more open and linked to reasoning. In fact the separation of discovery from justification could inhibit education.

What are the major challenges and barriers that we might face during the preparation and implementation of a problem-based learning curriculum? Since the potential value of PBL in medical education was highlighted by Barrows and Tamblyn,[12] its educational strategy has attracted increasing attention. Medical and professional schools have adopted PBL as a major feature of their programs, established schools have incorporated it in curriculum revisions and reports on higher education have featured PBL among recommendations as to good practice. For example, PBL has been adapted in the fields of Nursing, Social Work, Engineering and Architecture,[7,8,13,14] as well as Law, Teaching, Optometry and Management.[15,16] However, the implementation of PBL was associated with several challenges. Table 1 summarizes the major challenges/barriers experienced during the implementation of problem-based learning in a wide range of professional sciences. A brief summary of major challenges/barriers is discussed under this section.

Programs are resources intensive and time consuming. One question that must be asked before implementing any new educational innovation is whether the costs of changing the curriculum and then maintaining the new program will be justified in terms of learning effectiveness and efficiency. There are many factors to be considered in assessing cost: time commitments of faculty and students, requirements for support personnel, cost of instructional materials, necessary physical support (such as buildings and rooms, euch as[17] Barrows recommended a close look at both cost and feasibility before embarking on PBL.[18] Attention should be paid to those physical facilities, which might interfere with the success of PBL. Enhanced student learning and improved professional education should outweigh the initial costs due to refurbishment, for instance.[5] Problem-based learning is resource-intensive and requires much liaison which is time-consuming.[13] In particular case planning was very time-consuming and planning of the detailed content of each semester has taken an average of about 50 hours of meetings, spread over an academic year, together with substantial amounts of work between meetings.[19] Problem-based learning programs were also criticized because delivery to large groups required a large investment of staff time.[14,15,19] Concerns about student-directed learning and a lack of structure compiled with loss of faculty control and time constraints were problems noted by Berkson.[20] This author felt that the sustained attention to teaching required by PBL may act as barriers to implementation. In the phase of planning and implementation, a new curriculum will be rather more demanding than the old, but that is a temporary problem. Furthermore, the individuals teaching in a PBL curriculum allows increased tutoring by junior staff or even senior students, rather than senior staff. This will allow junior staff to benefit from their tutor role in their own professional development. Junior staff will less likely tend to start lecturing in the group discussion. This strategy will enhance small group function. The educational efforts of senior staff would be more profitable in curriculum development, in case construction and in lecturing.

Difficulties in integration. As discussed before one of the major objectives of PBL program is integration. However, integration is not an easy task. For example, Boshuizen et al found that behavioral sciences knowledge is less integrated in PBL curriculum, and can hence play a role of its own.[21] These findings are consistent with that of Hobus et al who found that behavioral sciences knowledge was not yet integrated with the clinical knowledge of doctors who had recently graduated, but was integrated with the clinical knowledge of more experienced doctors.[22] Research by Boshuizen et al suggests that sixth-year students may have behavioral science knowledge, but do not apply it in clinical reasoning.[23] The family doctors in that study appeared to have integrated this kind of knowledge with clinical knowledge. These studies clearly show that behavioral science knowledge may take more time to prove its relevance in clinical settings even in problem-based learning curriculum. Ostwald and Chen reported that it was difficult to integrate problems in architecture and creation of problems for the program was not an easy tack and it was not possible to integrate the whole curriculum in a problem-based learning format.[8]

Stress in problem-based learning students. Several studies have examined adaptation of medical/allied health and law students to conventional curricula.[24,25] However, few studies have explored the types and sources of stress associated with PBL in professional education. The approach in PBL is different from that used in conventional education. In conventional courses students are often accustomed to specific faculty objectives and directions about the content to be mastered. This is in contrast to PBL students where the philosophy is mainly student-centered and the students are expected to determine their own learning objectives and access appropriate literature resources. Students have to complete with many other applicants to be accepted in PBL programs. Learning collaboratively in small group environment brings its own stress because of uncertainty and lack of specificity about the depth and the breadth of their learning needs.[26] The competitive attitude in conjunction with the different personalities, learning styles, expectations

and uncertainty produce tensions in a small group not normally experienced in a traditional course. Pressure in these students could be unavoidable, continual and very tiring.[27] It may take students approximately 6 months to adopt to the new learning situation provided by PBL.

Difficulties in identification of appropriate tutor. One issue is the identification of appropriate tutors for PBL to facilitate teaching in small groups. Should the tutor be an expert in small-group work? Should the tutor be an expert in the content material? Should the tutor be expert in both? Research results are unequivocal. For small groups to function effectively, the facilitator must be familiar with teaching techniques of facilitating small groups.[12] Similarly, Eagle et al found that it is important for tutors to be well informed about a problem and about related learning issues.[28] Wilkerson et al looked at the effect of facilitating teaching with content expertise tutors on small group-performance.[29] Their findings suggest that content expert tutors have a more directive role which may endanger one of the most important aspects of small-group work. The development of students' skill in active and self-directed learning. Silver and Wilkerson data clearly show that expert tutors in PBL sessions talked too often and too long, and provided directs answers to students' questions and suggested more topics for discussion in the group.[30] Thus, the available evidence from these studies suggests that expert facilitators in small-group discussions spend more time on generating learning issues than students would spend on resolving them. Schwartz et al found that tutor's tutoring skills are much more important in facilitating student learning than the tutor's experience in the content of the problems.[31] However, Davis et al found that students' evaluation and performance were higher in groups led by content experts than in groups led by non-experts.[32] Their findings suggest that students with more directive tutors, enjoyed the PBL groups more, rated PBL as an efficient in structural method, were more able to identify gaps in their own knowledge and apply relevant information to the problem. Good group guidance by the tutor has been correlated with effective group discussion in PBL programs.[33-35]

Dysfunctional group in problem-based learning programs. Successful small-group teaching depends on the presence of three features displayed by group members. The most important feature of small-group work is than interaction should take place among all members present. Levels of participation may vary among members. However, it is important that there is some participation by all members.[36] A significant aspect of group work is the response of participants to other members in the group. Second, the group must have a clearly, defined task. Unclear objectives can cause frustration for the tutor as well as the students. Third, learning in small groups should depend on experience and reflection to modify behavior accordingly.[37] Lack of these characteristics if not corrected early, may result in group dysfunction and disturb the learning process of the group.[15] It is important to note that the success of the group to achieve its goals is not dependent only on the skills of the facilitator or the performance and collaboration of the members of the group. The design of the problem and its relevance to the learning topics and lectures related to the problem is also important for effective group performance.[38,39] Thus, the factors responsible for group dysfunction are (a) Tutor-associated problems (such as lack of adequate preparation for tutorials, tutorial domination, tutorial bias towards students who dominate the discussion, and inexperienced tutors or lack of proper knowledge regarding problem-based learning approach); (b) Student-associated problems (e.g., negative attitude towards each other, poor communication skills, lack of appreciation and support of each other, distraction/ stress in the group, unresolved personal conflict, and laxity in getting tasks completed in time; (c) Problems associated with design of PBL problems (e.g., inadequate design of PBL problems and lack of information in the Trigger, the Tutors Guide or Patient Data Sheet, discrepancy between faculty and students' objectives. Failure to address these problems adequately will affect the learning process of the students in PBL programs.[40]

Do problem-based learning students develop clinical reasoning and the cognitive abilities similar to that of expert doctors? In PBL programs, to achieve the objectives of developing effective clinical reasoning and cognitive abilities, problems included in curriculum must assist students in developing skills to drive thorough lists of hypotheses and test them with focused databases similar in quality to those that an expert would possess or obtain.[41] Studies have shown that the ways medical students think do not match with those of expert doctors.[42] According to these studies, experts rapidly generated hypotheses from the beginning of the encounter with the patient, and often tested several hypotheses simultaneously. They then made a functional enquiry and a review of symptoms and followed up any new clues or hypotheses, which were generated by these procedures. Norman similarly noted that experts generate better hypotheses and have a better fund of appropriate knowledge.[43] Whether students for PBL and conventional curricula use different methods of reasoning has only been assessed in one study at McMaster and McGill.[44] The authors described the PBL students as tending to "reason backwards from clinical information to theory and producing extensive elaboration about the data". The conventional curriculum students tended to "reason forward from theory" and stayed closer to the clinical facts. Also the PBL students explained the causes/

mechanisms of the cues included in the problem but made more diagnostic errors.[44] Boshuizen et al using a similar task, found that PBL students are able to provide extensive causal reasoning but made fewer diagnostic errors.[45] Albanese and Mitchell believe that evaluations of PBL graduates by their supervisors tend to be at least as good as those of graduates from conventional curricula, if not better.[46] It would seem likely that if PBL graduates had serious weakness in their abilities to analyze patient problems and achieve diagnosis, this would become evident to their faculty supervisors and should be reflected in residents' clinical evaluations. Unfortunately, clinical evaluation represents a complex mix of information based upon a multitude of personal and secondary observations of residents. It is difficult to sort out the influence of personal qualities and clinical skills from that of problem-solving qualities. For example, it has been shown that when students' personality characteristics and cognitive abilities are used together in assessment, the prediction of academic success is improved.[47,48] Grover and Smith reported that achievement is maximized at a certain level of anxiety, and anything above or below this point decreases the level of achievement.[49] Recently, Shen and Comrey demonstrated that the students' personality traits contributed significantly to the prediction of their medical school cognitive performances.[50] Thus differences in personal qualities could be an

Table 2 - Effects of PBL students' attitudes, achievements and performance outcomes.

Location	Number of participants	Type of course	Major Results	p-value	Research design	Reference
University of Southern Illinois, USA	47/154	Integrated PBL	- No difference in USMLE results	NS	Own control	Disttehorst and Robbs (1998)[55]
University of Kentucky, USA	35/22	PBL-surgery	- Improved performance - No difference in MCQs (final)	S NS	Own control	Schwartz et al (1992)[56]
University of Dalhousie, Canada	72/52	Case-oriented Problem-based stimulated (COPS) curriculum	- Students showed desirable attributes	S	Own control	Kaufman and Mann (1997)[58]
University of Uppsala, Sweden	113/72	Integrated PBL	- Students showed improvement in attitudes - Encouraged critical thinking	S S	Own control	Birgeggard and Lindquist (1998)[57]
The Finders University of South Australia	60	Non-integrated PBL (Medicine Year IV)	- Student valued clinical focus - Students performed better in clinical cases	-	No control	Barrington et al (1997)[68]
University of Kentucky, USA	-	PBL-surgery	- Performed better in problem solving - Performed better in clinical skills	-	No control	Shwartz et al (1997)[31]
Indiana University School of Medicine	30/45	PBL-segmental integration (Medicine, first 2 years)	- Performed as well as or better in NMBE I or USMLE I	-	Own control	Sivam et al (1995)[69]
Texas A & M University College	122/0	Computer-based in veterinary neuroanatomy	- Improved diagnostic efficiency -Accelerated	S	Internal control	Farnsworth (1997)[70]

PBL - Problem-based learning
MCQ - Multiple Choice Questions
USMLE - United States medical Licensing Examinaion
NMBE - National Medical Board Examination
S - Significant NS - Not significant

interfering factor in the evaluation of cognitive skills of PBL students. However, this issue needs substantially more studies before a definitive answer can be made. The effect of selection of students for courses based on problem-based learning should be considered in the evaluation process.

To what extent are problem-based learning students competent in basic and clinical sciences? Critics have voiced concern that the introduction of PBL may detract students from the traditional rigor of the basic sciences and question the efficiency of problem-based learning formats in facilitating knowledge acquisition. Recently, Colliver found that the research evidence either did not support the view that PBL improved the knowledge base or the clinical performance of students, or did not show significant improvement to justify the resources involved in running a PBL course.[51] He argues that the effect size (ES) seen with PBL have not lived up to expectations (0.8-1.0) and the theoretical basis for PBL is week.[51] These views have stimulated experts in medical education to respond.[52,53] They agree with the view that further research is required to illuminate both theory and practice of problem-based learning but they differ substantially in their interpretation of evidence regarding the usefulness of PBL in medical education.[52,53] Albanese for example, believes that an effect size of 0.8-1.0 is unreasonable expectation from PBL course, because (1) the degree of change that would be required of individuals would be excessive, (2) medical students are selected on the basis of their success in a traditional curriculum, and expecting them to do better in a PBL curriculum than in a traditional curriculum is an unreasonable expectation, and (3) the average study reported in the literature and accepted medical procedures and therapies are based upon studies having lesser effect size (ES).[52] Norman and Schmidt believe that it is important to use a broad range of educational research designs and variables than to relay on randomized controlled trials.[53] This approach will ensure better assessment of the outcomes of PBL programs. The data from Eisensteadt et al show that the short-term performance of PBL students on an objective, multiple-choice examination was inferior to those in the traditional class.[54] This observation is not unexpected. Indeed it is logical to assume that competent lectures highlighting important objectives for successfully answering multiple-choice questions offer more efficient means of examination preparation, especially if questions rely more on specific recall of facts rather than interpretation of data or other higher intellectual tasks. While it seems to be generally true that PBL students performed less well on basic science multiple-choice tests, not all PBL curricula have experienced declines in basic sciences test scores. The results of two studies suggests that the level of performance of PBL students in the United States Medical Licensing Examination (USMLE) Step I (a comprehensive integrated examination covering basic medical sciences) and the final year multiple-choice questions were as well as those of conventional curriculum students.[55,56] Furthermore, PBL students performed better in clinical assessment compared to conventional curriculum students. The difference was statistically significant.[55,57] The study by Birgegard and Lindquist have shown that PBL encouraged critical thinking and students demonstrated improved in attitudes.[57] Kaufman and Mann found similar positive attitudes in PBL students.[58] The difference again was statistically significant. Also the data of Eisensteadt et al show that long-term retention of information measured two years later was no different between PBL students and traditional class students, suggesting that the advantage arising from lecture-style preparation was short-lived and that the overall learning from PBL participation was better retained.[54] It is possible that the differences in the results of these studies may not be strictly due to the measurement procedure. It is possible that students directing their own learning spend considerable amounts of time studying topics that, although useful, are not considered by basic science faculty to be central or develop misconception because of the limited feedback available.

Do problem-based learning students become overtly dependent on a small-group environment? Albanese and Mitchell raised the issue that PBL students do learn by working on problems in groups.[47] These groups undoubtedly become cohesive as the students experience the joy and pain of medical school. Problems are solved by dividing the work and having each student learn one aspect, which he or she is expected to bring back and teach the other members in the group. After graduation, suddenly students find themselves thrust in the situation of having to do everything for themselves. The identification of learning needs now is an individual activity and there is no group to serve as a sounding board or share in the information research. The student is on his or her own to solve problems. The authors used the findings of Tolnai to support their views.[59] Tolnai found that PBL graduates were less likely to be in solo practice or practicing in a rural setting. The data may suggest that PBL graduates, who have learned to work in a group-oriented environment, are less likely to accept isolation when compared to graduates from a conventional curriculum. These findings although interesting cannot provide per se strong evidence for the argument. There are no studies, to my knowledge, in the medical literature review that support the notion that PBL graduates cannot work independently or are overtly dependent on a small-group environment.

However, the concern that PBL fosters dependence on the group environment has merit and should be addressed in research work.

Can problem-based learning be a panacea for all current challenges in medical education? The issue of content coverage in PBL, for example, may be critical for some in deciding whether and to what extent to implement PBL. The question is whether PBL covers an adequate range of content. The fact that students may set their own study agenda places a tremendous amount of importance on ensuring that they are able to identify knowledge deficiencies and search for and learn new knowledge effectively. There is evidence that students are uncomfortable with this aspect of problem-based learning.[47] Over half of the graduates of McMaster University over the period 1972 through 1977 described the lack of definition of the core material as a deficiency in the curriculum.[60] This lack of clarity of the objectives of PBL has been reported by students in other studies and this could reduce the quality of learning in PBL programs.[61,62] It appears that PBL enhances depth of learning but not breadth.[61-64] Therefore, the goal of curriculum designers should be to use problems that will lead students to the content the faculty wants them to thoroughly master the most and that will be most important to them in their clinical practice. Also, attempts to cover all content that students encounter in medical school through PBL may not be efficient or achievable. The role of group dynamics in determining the degree of content coverage by the small group should not be ignored and therefore, optimal methods of selecting members of the group and mechanisms by which we can identify dysfunctional groups may be an important issue to ensure successful content cover by the members of the group.[38-40,47] Furthermore, Eaton and Cottrell provided some evidence to support the hypothesis that different teaching techniques may be more effective for improving different elements of skills learning.[65] A highly structured technique involving breaking complex tasks down into smaller components and utilizing an internal "commentary" may be an effective way of teaching the sequential motor components of complex clinical skills. Their data suggests the need for different teaching techniques to enhance skill acquisition of medical students.

In conclusion, the challenges and the barriers discussed in this paper should not be considered as reasons for opposing PBL in curriculum innovation but rather as significant issues that need close attention and further research. Resource limitations and other constraints may force some medical schools with PBL curricula to revert to traditional learning methods. Yet advances in educational technology, such as computer-assisted learning may well lessen the resource demands of PBL and make it more attractive to larger institutions. Problem-based learning is not a panacea for all current problems in medical education. Designer of medical curricula should understand the needs for combining PBL with other efficient means of teaching, particularly for areas that can not be integrated or covered adequately in PBL.

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References

1. Eisenberg L. Science in medicine: too much or too little and too limited in scope? Am J Med 1988; 84: 483-491.
2. Mennin SP, Kaufman A. The change process and medical education. Medical Teacher 1989; 11: 9-16.
3. Grant JR, Gale R. Changing medical education. Medical Education 1989; 23: 252-257.
4. Fullan M. The new meaning of educational change. London: Cassel; 1991.
5. Aldred SE, Aldred MJ, Walsh LJ, Dick B. The direct and indirect costs of implementing problem-based learning into traditional professional courses within universities. Evaluation and Investigation Program Higher Education Division, Department of Employment, Education, Training and Youth Affairs. Canberra 1997.
6. Grant RJ, Gale R. Leading educational change. Journal of Course Organizers 1990; 5: 63-71.
7. Ryan G, Little P. Innovation in a nursing curriculum: A process of change. In: Boud D, Feletti G, editors. The challenge of problem-based learning. London: Kogan Page; 1991. p. 87-101.
8. Ostwald MJ, Chen SE. Marginalization of theoretical issues in a professional PBL courseæa structural or attitudal problem? In: Chen SE, Cowdroy RM, Kingsland AJ, Ostwald MJ, editors. Reflections on problem-based learning. Australia: Australian PBL Network; 1995.
9. Ostwald MJ. Within the margins: Problem-based learning and the history/theory gap. In: Fung S, Jackson M, editors. Teaching theories/architectural history. Forthcoming: University of South Australia; 1994.
10. Ostwald MJ. Within the margins: Between political and educational dimensions. In: Fung S, Jackson M, editors. Teaching theories/architectural history. Australia: University of South Australia; 1994.
11. Nickles T. Introductory essay: scientific discovery and the future of philosophy of science. In: Nickles T, editor. Scientific discovery, logic and rationality. New York: Reidel; 1980.
12. Barrows HS, Tamblyn RM. Problem-based learning: An approach to medical education, Series on Medical Education, New York: Springer Verlag; 1988.
13. Heycox K, Bolzan N. Applying problem-based learning in first year social work. In: Boud D, Feletti G, editors. The challenge of problem-based learning. London: Kogan Page; 1991.
14. Cawley P. The introduction of a problem-based option into a conventional engineering degree course. Studies in Higher Education 1989; 14: 83-95.
15. Lovie-Kitchen J. Problem-based learning in optometry. In the challenge of problem-based learning. In: Boud D, Feletti G, editors. London: Kogan Page; 1991.

16. Boud D, Feletti G. Introduction, In: Boud D, Feletti G, editors. The challenge of problem-based learning. New York: St Martin's Press; 1991. p. 5-15.
17. Mennin SP, Martinez-Burrola N. The cost of problem-based vs. traditional medical education. Medical Education 1986; 20: 187-194.
18. Barrows HS. Practice-based learning: Problem-based learning applied to medical education, Springfield: Ill: Schoool of Medicine 1994.
19. Benbow EW, Rutishauser S, Stoddart RW, Andrew SM, Freemont AJ. Pathologists and problem-based learning. J Pathol 1996; 180: 340-342.
20. Berkson L. Problem-based learning: Have the expectations been met? Academic Medicine 1993; 68: S79-S88.
21. Boshuizen HPA, Van der Vleuten CPM, Schmidt HG, Machiels-Bongaerts M. Measuring knowledge and clinical reasoning skills in a problem-based curriculum. Medical Education 1997; 31: 115-121.
22. Hobus PPM, Schmidt HG, Boshuizen HPA, Patel VL. Contextual factors in the activation of first hypotheses: Expert-novice differences. Medical Education 1987; 21: 471-476.
23. Boshuizen HPA, Schmidt HG, Custers EJFM, Van de Wiel MW. Knowledge development and restructuring in the domain of medicine: The role of theory and practice. Learning and Instruction 1995; 5: 269-289.
24. Clark E, Rieker P. Gender differences in relationships and stress of medical and law students. Journal of Medical Education 1986; 61: 32-40.
25. Hiens M, Fahey S, Leidon L. Perceived stress in medical, law and graduate students. Journal of Medical Education 1984; 59: 169-179.
26. Miller J, Trimbur J, Wilkes J. Group dynamics: Understanding group success and failure in collaborative learning. New Directions for Teaching and Learning 1994; 59: 33-44.
27. Reinders S. Problem-based learning from a students' point of view. In: Bouhuijs P, Schmidt HG, Van Berkael H, editors, Problem-based Learning as an educational strategy, Maastricht, Netherlands: Network Publications, 1993.
28. Eagle CJ, Harasym PH, Mandin H. Effects of tutors with case expertise on problem-based learning issues, Academic Medicine 1992; 67: 465-469.
29. Wilkerson L, Hafler JP, Lin PA. Case study of student-directed discussion in four Problem-based Tutorial Groups. Proceedings of the Thirtieth Annual Conference on Research in Medical Education. Academic Medicine 1991; 66: S79-S81.
30. Silver M, Wilkinson L. Effects of tutors with subject expertise on the problem-based tutorial process. Academic Medicine 1991; 66: 298-300.
31. Schwartz RW, Burgett JE, Blue AV, Donnelly MB, Sloan DA. Problem-based tutorial process. Academic Medicine 1991; 66: 298-300.
32. Davis WK, Nairn R, Paine ME, Anderson RM, Oh MS. Effects of expert and non-expert facilitators on the small group process and on student performance. Academic Medicine 1992; 67: 470-474.
33. Bhattacharya N. Students' perceptions of problem-based learning at the BP Koirala Institute if Health Sciences, Nepal. Medical Education 1998; 32: 407-410.
34. Dolmans DHJM, Wolfhagen IHAP, Schmidt HG, Vleuten CPM. A rating scale for tutor evaluation in a problem-based curriculum: Validity and reliability. Medical Education 1994; 25: 550-558.
35. Gijselaers WH, Schmidt HG. Development and evaluation of a causal model of a problem-based learning. In: Nooman ZM, Schmidt HG, Ezzat ES, editors. Innovation in Medical Education: An evaluation of its present status, New York: Springer-Verlag; 1990. p. 95-113.
36. Crosby J. AMEE Medical Education Guide: Learning in small group. Number 8. Medical Teacher 1996; 18: 189-202.
37. Boud D, Keogh R, Walker D. Reflection: Turning experience into learning. London: Koga Page; 1995.
38. Rono F. A students' review of the challenges and limitations of problem-based learning. Education of Health 1997; 10: 199-204.
39. Dolmans DH, Snelkn-Bellendong H, Wolfhagen IHAP, Van der Vleuten CPM. Seven principles of effective care design for a problem-based curriculum. Medical Teacher 1997; 19: 185-189.
40. Hitchcock MA, Anderson AS. Dealing with dysfunctional tutorial groups. Teaching and Learning in Medicine 1997; 9: 19-24.
41. Thomas R. Problem-based learning: measurable outcomes. Medical Education 1997; 31: 320-329.
42. Barrows HS, Norman GR, Neufield VR, Feightner JW. The clinical reasoning of randomly selected physicians in general medical practice. Clinical and Investigative Medicine 1982; 5: 49-55.
43. Norman GR. Problem-solving skills: Solving problems and problem-based learning. Medical Education 1988; 22: 279-283.
44. Patel VL, Groen GJ, Normal R. Effects of conventional and problem-based medical curricula on problem solving. Academic Medicine 1991; 66: 380-389.
45. Boshuizen HPA, Schmidt HG, Wassmer L. Curriculum style and the integration of biomedical and clinical knowledge, In: Bouhuijs PAJ, Schmidt HG, Van Berkel HJM, editors, Problem-based Learning as an Education Strategy. Maastricht, the Netherlands: Network Publications; 1994: 32-42.
46. Albanese MA, Mitchell S. Problem-based learning: A review of literature on its outcomes ad implementation issues. Academic Medicine 1993; 68: 52-81.
47. Hojat M, Robeson M, Damjonov I, Veloski JJ, Glaser K, Gonnella JS. Students' psychosocial characteristics as predictors of academic performance in medical school. Academic Medicine 1993; 68: 635-637.
48. Aldrich CK. Psychiatric interviews and psychological tests as predictors of medical students' success. Journal of Medical Education 1987; 62: 658-664.
49. Grover PL, Smith DU. Academic anxiety, locus of control, and achievement in medical school. Journal of Medical Education 1981; 56: 727-736.
50. Shen H, Comrey AL. Predicting medical students; academic performances by their cognitive abilities and personality characteristics. Academic Medicine 1997; 72: 781-786.
51. Colliver JA. Effectiveness of problem-based learning curricula: research and theory. Academic Medicine 2000; 75: 259-266.
52. Albanese M. Problem-based learning: why curricula are likely to show little effect on knowledge and clinical skills. Medical Education 2000; 34: 729-738.
53. Norman GR, Schmidt HG. Effectiveness of problem-based learning curricula: theory, practice and paper darts. Medical Education 2000; 34: 721-728.
54. Eisenstaedt RS, Barry WE, Glanz K. Problem-based learning: Cognitive retention and cohort trials of randomly selected participants and decliners. Academic Medicine 1990; 69: S11-S12.
55. Distlehorst LH, Robbs RS. A comparison of problem-based learning and standard curriculum students: Three years retrospective data. Teaching and Learning Medicine 1998; 10: 131-137.
56. Schwartz RW, Donnelly MB, Nash PP, Young B. Developing student's cognitive skills in a problem-based surgery clerkship. Academic Medicine 1992; 67: 694-696.
57. Birgegard G and Lindquist U. Change in student attitudes to medical school after the introduction of problem-based learning in spite of ratings. Medical Education 1998; 32: 46-49.
58. Kaufman A, Mann KV. Basic sciences in problem-based learning and conventional curricula: students' attitudes. Medical Education 1997; 31: 177-180.

59. Tolnai S. Continuing medical education and career choice among graduates of problem-based and traditional curricula. Medical Education 1991; 25: 414-420.
60. Woodward CA, Ferrier BM. Perspective of graduates two or five years after graduation from a three-year medical school. Journal of Medical Education 1982; 57: 294-302.
61. Sadlo G. Problem-based learning enhances the educational experience of occupational therapy students. Education for Health 1997; 10: 101-114.
62. Ramsden P. Learning to teach in higher education. London: Routledge; 1992.
63. Coles CR. Differences between conventional and problem-based curricula in their students' approach to studying. Medical Education 1985; 19: 308-309.
64. Newble DI, Clarke RM. The approaches to learning of students in a traditional and in an innovative problem-based medical school. Medical Education 1986; 20: 267-273.
65. Eaton DM, Cottrell D. Structured teaching methods enhance skill acquisition but not problem-solving abilities; An evaluation of the "silent run through". Medical Education 1999; 33: 19-23.
66. Solman P, Finch E. A qualitative study identifying stressors associated with adapting to problem-based learning. Teaching and learning in Medicine 1998; 10: 58-64.
67. Rand JS, Baglioni AJ Jr. Subject-based problem-based learning in the veterinary science course at the University of Queensland. Australian Veterinary Journal 1997; 75: 120-125.
68. Barrington D, Wing L, Latimer WK, Aplens J, Prideaux D. Evaluation of a change for traditional case studies to patient-based, problem-based learning: a case study. Medical Teacher 1997; 19: 104-116.
69. Sivam SP, Latridis PG, Vaughan S. Integration of pharmacology into problem-based learning curriculum for medical students. Medical Education 1995; 29: 289-296.
70. Farnsworth CC. Measuring the effects of problem-based learning on the development of veterinary students' clinical expertise. Academic Medicine 1997; 72: 552-554.