Chapter 4
Problem-Based Learning

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Problem-based learning (PBL) was created at McMaster University almost 40 years ago. It has changed medical education in ways that would not have been foreseen. It has supplanted the traditional lecture-based learning model in many medical schools and has expanded around the world and beyond medical education into a host of other disciplines. It has also galvanized the push to get students out of the lecture hall and into more interactive learning settings. This chapter is designed with two purposes in mind: to help a medical teacher decide whether to use PBL in either their course or broader medical curriculum and, having decided to use PBL, help them prepare for their role as a teacher in a PBL course. Teaching in a PBL course is a much different experience than in almost any other teaching format. As Howard Barrows, the person most closely associated with the broad adoption of PBL, liked to say, rather than "being a sage on the stage, you are a guide on the side." This takes some getting used to, particularly if you like being a sage and/or you crave the stage, or you just have never experienced a form of teaching where you were not THE authoritative source.

Definition of PBL

PBL can be characterized as an instructional method that uses patient problems as a context for students to acquire knowledge about the basic and clinical sciences. It is most commonly associated with small group learning in which the instructor serves as a facilitator. As a facilitator, the instructor's role is to ensure that the process of PBL is carried out, not to dispense knowledge. The process of PBL is to place the focus on the students and to allow them free inquiry into how to solve the problem. Specifically, the facilitator has three tasks: to help students organize their group to

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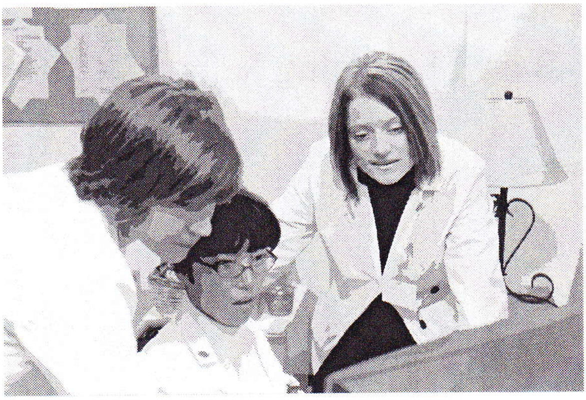


function effectively, to ensure that all members of the group have an opportunity to participate fully, and to adjust their course if they deviate too far from the desired path. Originally, PBL was designed to be an overarching curriculum that required a major reallocation of time allotted to various educational activities. After the time for structured activities was reduced, there was a major restructuring in how the remaining required time was allocated to lecture, small group, lab, etc. A number of medical schools maintain two curriculum tracks, one traditional lecture-based and the other PBL. In recent years, there has been a trend for schools that have dual tracks to merge them into one, adopting the best of both curricula into a single combined "hybrid" curriculum. There have also been efforts to institute PBL in individual courses embedded within curricula that employed largely lecture-based learning methods.

Research on the effectiveness of PBL has been somewhat disappointing to those who expected PBL to be a radical improvement in medical education. Several reviews of PBL over the past 20 years have not shown the gains in performance that many had hoped for; such studies have been limited by design weaknesses inherent in evaluating curricula. While the research indicates that PBL curricula have not produced graduates who are demonstrably inferior to graduates of other types of curricula; whether they are superior is an open question. There is some evidence that students from a PBL curriculum function better in clinically related activities and students and faculty consistently report enjoying learning and teaching in a PBL format. However, there has been concern expressed that students in a PBL curriculum may develop less complete cognitive scaffolding for basic science material. This may relate to the somewhat disconcerting trend that approximately 5–10% of students do not do well in a PBL curriculum. If able these students often change tracks after having difficulty in the PBL track. However, as schools have merged tracks into hybrid curricula, it is not clear yet how such students will do in the hybrid.

Introducing PBL into the Curriculum

The challenges likely to be encountered in implementing PBL depend to a large degree upon the scope of implementation that is being considered. If it is a change in the entire medical curriculum, it will be a much different process than if a course director is deciding whether to implement it in his/her course. In either case, a review of the evidence for and against PBL would be an important first step. The gains that are hoped for will need to be weighed against the cost to make the change. The arguments used for changing to PBL will be more compelling if they are buttressed by evidence. This will be especially important if the change is to be curriculum-wide as opposed to a single course. There were three reviews published in 1993 that have generally served this purpose. Vernon and Blake (1993) reported a meta-analysis of controlled trials, Albanese and Mitchell (1993) reported what might be considered a best evidence synthesis and Berkson (1993) conducted a thematic review. There have been more recent reports in the literature that postulate that a large degree of change should be expected from PBL to offer sufficient evidence (Colliver, 2000; Cohen, 1977). While the outcomes have not been overwhelmingly different for PBL, what may give PBL an edge over lecture-based learning is the ability to exercise greater control over the content and information density of the curriculum. Adding a lecture or making an existing lecture more dense (curriculum creep) can be done with little or no fanfare in a lecture-based curriculum. In contrast, increasing the number of problems or changing the nature of a problem to make it more information dense would demand careful consideration by PBL curriculum managers. The added scrutiny that changes demand in a PBL curriculum puts a damper on curriculum creep.

If you wish to implement PBL in your class, you should consider how to do this within the larger curriculum and the physical space and teaching constraints. Students need to have the ability to meet together in small groups with a facilitator and have access to information resources. Implementation in a course is also challenging because the types of problems that take the fullest advantage of the PBL structure tend to be multidisciplinary. The ideal situation is to have dedicated space for each small group that is equipped with technical support that allows internet access, electronic capture of white-board writing, and refreshments. However, this level of support is unlikely to be feasible in a single class use of PBL and the logistics of using multidisciplinary cases in a single course can be extremely difficult to manage. However, with some creativity and relaxing of the generally accepted requirements, it has been done (see Farrell et al., 1999).

Implementation across the entire medical school curriculum takes substantial effort. In schools that have made a major shift to PBL, the impetus or at least unquestioned support of the medical school Dean has been a driving force. There are resource allocation issues for space, faculty salary support and technical support that make any such implementation without the Dean's full support virtually impossible. Consensus among faculty is critical to begin implementation. The evidence and reviews cited earlier have been helpful to the governing bodies that have made such decisions. New medical schools have had the most success in starting PBL curricula (e.g., McMaster, Florida State University). There have been cases where whole medical school curricula have been converted to PBL, examples include the University of Iowa College of Medicine, Sherbrooke University, and the University of Missouri-Columbia. More commonly, schools have adopted a PBL track, in which admission is competitive and only a fraction of the entire class who volunteer and apply for the PBL track are admitted. Examples of this approach include Southern Illinois University, University of New Mexico, Harvard University and Michigan State University. The advantages of adopting a track approach are that it does not require a commitment from all faculty, small groups can usually be accommodated more easily, the value and feasibility of PBL can be demonstrated for those who have doubts, and all of the "bugs" in the PBL system can be worked out in a more controlled manner. In many cases, schools that began by adopting a track have eventually merged the PBL and traditional tracks into a hybrid that looks more like PBL than the traditional lecture-based learning curriculum.

Curriculum and Course Design

According to Barrows (1985), PBL is most compatible with an organ-based curriculum, in which courses are aligned with different organs of the body. Thus, a course on the cardiovascular system would have the anatomy, physiology, biochemistry, etc. of the cardiovascular system all integrated. Because patient problems are often localized to a single organ system, it seems logical that PBL would be consistent with an organ-based curriculum. For a course embedded in a lecture-based learning curriculum, those courses that are clinically focused are most compatible with a PBL format. In this type of curriculum, adopting PBL in basic science courses such as biochemistry or physiology will be more difficult due to the limited focus of the course. Integrating concepts that are the focus of other courses into the PBL cases of your course can be challenging to coordinate at the very least.

PBL Definitions

Before going into the larger issues of how to support PBL course design, it will be helpful to give a more specific definition of what has been considered the prototype PBL process (reiterative PBL in Barrow's taxonomy, 1986).

1. The process begins with a patient problem. Resources accompanying the problem include detailed objectives, print materials, audiovisual resources, multiple choice self-assessment exercises and resource faculty.
2. Students work in small groups, sometimes called tutorial groups; 6–8 students per group is often recommended.

3. The small groups are moderated by one or more faculty facilitators (sometimes called tutors, I prefer to use the term facilitator because a tutor to me is someone with content expertise that is trying to individually teach a student).
4. Students determine their own learning needs to address the problem, make assignments to each other to obtain needed information and then return to report what they have learned and continue with the problem. This happens repeatedly as students secure more information and keep probing deeper into the problem.
5. Students return for a final debriefing and analyze the approach they took after getting feedback on their case report.
6. Student evaluation occurs in a small group session and is derived from input from self, peer and facilitator.

Although Barrows' reiterative PBL is probably the purest form of what has been called PBL, there have been many different approaches used. Dolmans et al. (2005) indicate that "Although PBL differs in various schools, three characteristics can be considered as essential: problems as a stimulus for learning, tutors as facilitators and group work as stimulus for interaction" (p. 735). While the "McMaster Philosophy" had three key features: self-directed learning, problem-based learning, and small group tutorial learning, the only characteristic that is common among PBL forms is that learning is based upon patient problems.

PBL Problems

From a curriculum or course design perspective, you have to be clear about what you want to accomplish from PBL and plan accordingly. The focal points of curriculum planning are the PBL problems. The content of the problems needs to be carefully considered as well as the organization and timing.

There are 7 qualities of an appropriate problem that have been delineated:

1. Present a common problem that graduates would be expected to be able to handle, and be prototypical of that problem.
2. Be serious or potentially serious – where appropriate management might affect the outcome.
3. Have implications for prevention.
4. Provide interdisciplinary input and cover a broad content area.
5. Lead students to address the intended objectives.
6. Present an actual (concrete) task.
7. Have a degree of complexity appropriate for the students' prior knowledge (Albanese and Mitchell, 1993).

The structure or format of the problem, sometimes called a case, provides room for much variability. They can range from brief paragraphs describing a symptom or set of symptoms (e.g., chest pain) to elaborate paper or computer simulations or even using simulated patients. They can be relatively unorganized, unsynthesized, and open-ended, or they can be relatively highly structured with specific questions that need to be addressed. Barrows (1985) suggests open-ended problems, which promote application of clinical reasoning skills, structuring of knowledge in useful contexts, and development of self-directed learning. In the same curriculum, some problems can be highly structured, particularly early in the curriculum and others unstructured, especially as students approach the end of the curriculum. An example of a type of problem that is relatively structured is the Focal Problem developed at Michigan State University. It starts with a written narrative of a clinical problem as it unfolds in a real-life setting. In this design, after descriptions of significant developments occur, "stop and think" questions are inserted for students to ponder. This approach helps students focus on the steps in the decision-making process used in solving problems that may have more than one viable solution (Jones et al., 1984; Wales and Stager, 1972; Pawlak et al., 1989). These varied problem designs and computer-based variants may all have a role at some point in a PBL curriculum. More structured formats might be better placed early in the curriculum when students will be challenged with even the simplest clinical scenarios while the lesser structured formats may be more effective after students gain clinical experience and comfort with the PBL method.

In curriculum design, you have to determine whether PBL will be used just for students to learn the basic sciences or whether it will continue into what are considered the clinical years. The topics and structure of the problems need to be carefully considered and tailored to the developing competency of students. The number of problems addressed needs to be considered. If problems are addressed in weeklong blocks, then the curriculum design for PBL is a sequence of problems equal to the number of weeks in the curriculum. The flow of the problems in terms of content, objectives and level of structure then becomes the backbone of the curriculum.

Student Groups

Next to the problems, the most important component of PBL is the grouping of students to work on the problem. As noted above, small groups of 6–8 are usually recommended. If the groups are too large, less assertive students have a reduced opportunity to provide input into deliberations and it gets difficult to schedule time for group meetings.

It is probably best to assign students to groups at random and to avoid including students who are couples (dating, married or otherwise related) in the same group. To the extent possible, groups should be comparable in their range of ability similar to the range for the entire class. It has become increasingly clear that just throwing a group of students together with a problem is not necessarily going to yield something useful. Guidelines and role assignments are often recommended to help students get a start in how to organize themselves to do productive work. Barrows (1985) (see pp. 60–61) recommends that students assume three separate administrative roles to make the process work smoothly: PBL reader, Action Master List Handler, and Recorder. New students should assume these roles with each new problem.

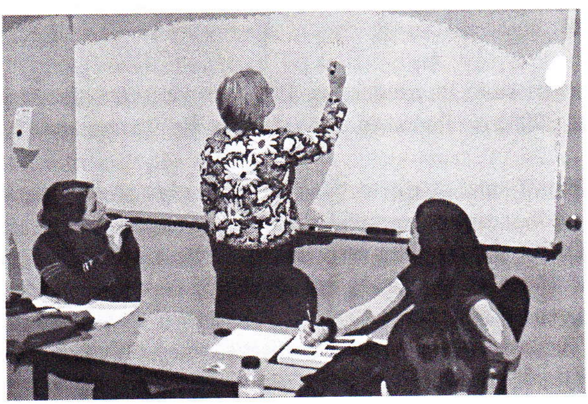
Effective groups establish basic norms of acceptable behavior. For example, the group should determine when interruption is permitted, the attitudes towards latecomers, whether eating is allowed during a session, what to do if the tasks for the day are completed early and so on. Technology is also becoming an issue for small group management and may interfere with problem-solving in any number of ways. Computers, cell phones, PDAs, MP3 players, etc., can all be used for distracting purposes. Ground rules for the use of technology should be part of the standards of acceptable behavior (e.g., no checking email, or receiving non-emergency phone calls during the session).

Small Group Facilitator

The next major participant is the facilitator(s). Who should be a facilitator has been a somewhat controversial matter. There is some evidence that having content "expert" facilitators improves student performance, especially early in the curriculum. However, it is unrealistic to have facilitators who are expert in all areas that are the subject of PBL cases. Some schools actively avoid selecting content expert facilitators to reduce student dependence upon them as information sources. Facilitators need knowledge sufficient to achieve a level of familiarity with the material. Typically facilitators need to work through a case 3 times to achieve what has been called "case expertness" (Zeitz and Paul, 1993).

What facilitators mostly need is adequate preparation for their role. They need to be given specific guidelines for how they are to interact with students. Moving from content expert to facilitator is not necessarily a natural act for many faculty, so having them practice their role during training will be helpful. The use of "standardized" students, a group of people who are trained to act like students, can make the practice closer to the real thing. However, it can be expensive and the fidelity of the simulation to real life may be difficult to maintain.

Facilitators should also be given all information about the case and any associated readings or materials that students will be given, but in addition, materials that will



allow them to be able to guide students in their search for knowledge. This includes the "next steps" that students are expected to take. If there are preparatory lectures, it will benefit the facilitators to attend. Anything that can help facilitators function in a facilitator role and achieve case expertness is useful.

Facilitators also need to be prepared for students' reaction to the experience. If students are used to having faculty serving as content deliverers, not facilitators, the transition to this type of relationship can be rocky. Facilitators need to be prepared for student frustration early in the process when the facilitator does not give them direct answers to their questions. Over time, students learn that the facilitator is explicitly not to be a source of answers to their questions, but early on it can be a difficult adjustment for students and facilitators.

How many facilitators per group (or how many groups per facilitator) is as much a practical consideration as one that is educational. The obvious answer is at least one facilitator per group would be ideal. However, faculty resources are often quite limited. A number of schools have successfully used more advanced students as facilitators or as a co-facilitator with a faculty member. There have also been studies that examined the impact of having faculty facilitate more than one group at once, circulating between them. When the facilitator cannot be with a group throughout its deliberations, it makes it difficult for the facilitator to re-engage with the group and it takes additional time that must be factored into the process. A circulating facilitator is also limited in their ability to ensure that there is balanced input from all members of the group and assess student contributions to the group process.

In summary, the qualifications of the facilitators are probably not as important as their familiarity and comfort with the cases. How many facilitators are needed depends upon how many groups and the number of facilitators used per group and the availability of facilitators. Advanced students have been used as co-facilitators with faculty to good advantage. Using fewer than one facilitator per group has significant trade-offs in terms of the facilitator's ability to manage disruptive or dysfunctional group dynamics and to evaluate student contributions to the group process.

PBL Process

The actual process used in conducting PBL can vary, but the Maastricht 7 Step method (Wood, 2003) is often used as a guide for facilitators and students:

Step 1 – Identify and clarify unfamiliar terms presented in the scenario; scribe lists those that remain unexplained after discussion.

Step 2 – Define the problem or problems to be discussed; students may have different views on the issues, but all should be considered; scribe records a list of agreed problems.

Step 3 – "Brainstorming" session to discuss the problem(s), suggesting possible explanations on basis of prior knowledge; students draw on each other's knowledge and identify areas of incomplete knowledge; scribe records all discussion.

Step 4 – Review steps 2 and 3 and arrange explanations into tentative solutions; scribe organizes the explanations and restructures if necessary.

Step 5 – Formulate learning objectives; group reaches consensus on the learning objectives; tutor ensures learning objectives are focused, achievable, comprehensive, and appropriate.

Step 6 – Private study (all students gather information related to each learning objective).

Step 7 – Group shares results of private study (students identify their learning resources and share their results); tutor checks learning and may assess the group.

Grading Student Performance

Evaluating student performance in PBL is challenging. To treat it adequately would take a separate publication all by itself, perhaps a text. One of the difficulties in evaluating PBL is that the process used to solve a problem is often as important as the solution reached. Further, problem-solving in a facilitated small group is a complex task that involves social interactions and that unfolds sequentially over time. Capturing such skills in an assessment is difficult. For example, knowledge assessments have been used to assess students in PBL curricula, but they do not lend themselves very effectively for capturing the interactions that occurred during the small group sessions. Facilitator ratings would probably be better, but having facilitators rate student performance can affect group dynamics. And, if students are used as facilitators or co-facilitators, the situation becomes even more complex.

Two measures are heavily linked to PBL that are worth describing: Triple jump exercise and Objective Structured Clinical Exams (OSCEs).

The primary goal of a triple jump exercise is to assess clinical problem-solving and self-directed learning skills. In a triple jump exercise, students discuss a written clinical scenario and identify the related learning goals, review the learning materials individually, and return to present their conclusions and judge their own performances. Students sometimes have 3 h to complete their exercise, sometimes a week. This type of assessment is often used for formative evaluation purposes. It is less often used for grading purposes because it is time consuming and limits the number of scenarios that can be evaluated. As a result scores tend to be contextually bound to the specific problem assessed. I personally think the name choice is unfortunate because it is too close to the negative term "jumping through hoops."

Objective Structured Clinical Examinations are performance-based examinations in which students rotate from station to station (Harden et al., 1975). At each station, students are required to do a particular task or sequence of tasks (e.g., interview a patient and perform a physical exam and then write up their assessment). There are two general types of OSCE stations, the long and short type. The long type of station can take up to a couple of hours to complete and is very extensive. The short type is much more focused and stations generally take from 10 to 15 min. The Clinical Skills portion of the United States Medical Licensure Examination Step 2 is of the short type. For the first 15 years of their existence, OSCEs were not widely adopted for high stakes evaluation purposes due to a pervasive problem with what was termed content specificity. Student performance varied quite markedly when even small changes in the nature of the content of a station were made. In the late 1980s and early 1990s, a series of studies (Colliver et al., 1989; Petrusa et al., 1991) applied generalizability theory to the problem. They were able to project acceptable reliability for OSCEs for making pass–fail decisions with at least 10 stations however, reliability was found to vary dramatically between schools (Berkson, 1993; Dolmans et al., 2005) and needs to be assessed with each application. OSCEs have achieved widespread adoption since that time. Stations often use standardized patients, computer simulations, literature search facilities, manikins, and other types of "hands-on" experiences. The strengths of the OSCE are its face validity and standardized clinical experience for all examinees. There are relatively few other ways of assessing complex skills and abilities such as communication skills with the same degree of standardization and reliability. The primary limitation of the OSCE pertains to the resources needed for implementation. For an in-depth discussion of the use of OSCEs in any curriculum, see Chapter 11. For readers who are interested in a thorough treatment of assessment of students in PBL, Nendaz and Tekian (1999) provide an overview. For an analysis of the strengths and weaknesses of various approaches to student assessment, see Chapter 11.

Resources

PBL can be resource intensive depending upon how it is implemented. However, a lecture-based learning curriculum is also resource intensive. It has been estimated that for class sizes less than 100, PBL may have a cost advantage (Albanese and Mitchell, 1993). However, the costs of computing and the like have come down since then, but faculty time has generally become more expensive. With the rising cost of faculty time for serving as facilitators, the breakeven point between lecture and PBL has become less favorable to PBL.

In the early implementations of PBL, small groups were given dedicated space. Those who have dedicated space generally think it is very important for creating a sense of group cohesion and giving the group a place to meet at any time. It also helps to justify the tuition that many schools charge! However, dedicated space in today's crowded health sciences learning centers can be hard to come by and increasingly hard to justify. As schools respond to the anticipated shortage of physicians by increasing class sizes, they will be even more hard-pressed to supply dedicated space for PBL groups. While it is not hard to see how dedicated space would be a desirable feature, it is not necessarily clear that the lack of dedicated space will have detrimental effects on student learning.

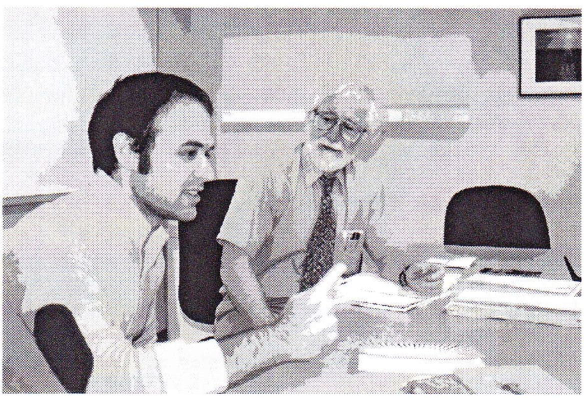
What all small groups will need is access to information resources. Having dedicated space for groups enabled institutions to furnish them with secured computers that could be used for searching the literature or the web. However, with the increasing availability of notebook computers and remote access to the web, dedicated space for information access is not as critical. Students can even meet at the local coffee shop and have web access, something they may actually prefer. Generally, each group should have at least one computer available during their meetings. The computer is needed for recording the proceedings and accessing information resources. If a single person serves as the recorder and manages access to the information resources, some of the potential problems associated with abuse of technology can be minimized.

A well-stocked library is an important need for students in a PBL curriculum. Nolte et al. (1988) found that library use of reserve books increased twenty fold after introducing a PBL course on neurobiology into the curriculum. With the more recent advent of the internet and online references, having internet access is essential. Literature search software such as PubMed is critical. Having general web-searching capability is useful for looking for non-library references such as policy statements and current events. However, as noted by Kerfoot and colleagues (2005), there need to be guidelines for internet usage to avoid having the problem solving process subverted by web searches and non-authoritative sources.

Also beneficial are white-boards or blackboards. Some schools have adopted electronic blackboards that enable electronic capturing of the material students write on the board.

Lectures can also be an instructional resource, but Barrows recommends limiting them to 1–1.5 h per day (Barrows, 1985). Barrows also recommends that basic science research faculty should be a resource available to meet with students for 4–6 h per week.

With new learners, there is a danger of having too many resource options. They can bog down looking for information and give too little attention to problem-solving. The facilitator should be quick to intervene should it happen.



The instructional environment in the small group should be informal and as low stress as possible. Lighting should be sufficient to see all the types of educational resources that will be shared. The environment (chairs) should be comfortable, but not so comfortable as to make it difficult for students to stay alert. Students should be able to bring food and drink into the meeting room. Ready access to a refrigerator and even microwave help to make the room comfortable.

Summary

Beginning a PBL curriculum is not for the faint-hearted. There is much infrastructure that needs to be put into place and there may be increased costs. While the effectiveness of PBL appears to be gaining better documentation and we are gaining a better understanding about how to do PBL, there is still much we need to learn. In the meantime, it is important to keep in mind what one is trying to accomplish with PBL. Based upon recent learning principles, Dolmans et al. (2005) identified four important processes (constructive, self directed, collaborative and contextual) underlying PBL that provide a good synopsis of what one is trying to accomplish. By a constructive process, it is meant that learning is an active process by which students "construct or reconstruct their knowledge networks." A self-directed process is one where learners are involved in planning, monitoring and evaluating the learning process. A collaborative learning process is one in which the social structure involves two or more students interacting in which they: have a common goal, share responsibilities, are mutually dependent and need to reach agreement through open interaction. A contextual process recognizes that learning is context-bound and that transfer to different contexts requires confronting cases or problems from multiple perspectives. No matter how one decides to ultimately implement PBL, it is important that they design their experience to keep clearly in mind what they are trying to accomplish and not get distracted from their goal.

References

Albanese MA, Mitchell S (1993) Problem-based learning: A review of literature on its outcomes and implementation issues. Academic Medicine 68: 52–81.

Barrows HS (1985) How to design a problem-based curriculum for the preclinical years. Springer, New York.

Barrows HS (1986) A taxonomy of problem-based learning methods. Medical Education 20: 481–486.

Berkson L (1993) Problem-based learning. Have the expectations been met? Academic Medicine 68: S79–S88.

Cohen J (1977) Statistical power analysis for the behavioral sciences, rev ed. Englewood Cliffs, Mahwah, NJ.

Colliver J (2000) Effectiveness of problem based learning curricula. Academic Medicine 75: 259–266.

Colliver JA, Verhulst SJ, Williams R, Norcini JJ (1989) Reliability of performance on standardized patient cases: A comparison of consistency measures based on generalizability theory. Teaching and Learning in Medicine 1(1): 31–37.

Dolmans DHJM, De Grave W, Wolfhagen IHAP, van der Vleuten CPM (2005) Problem-based learning: Future challenges for educational practice and research. Medical Education 39: 732–741.

Farrell T, Albanese MA, Pomrehn P (1999) Problem-based learning in ophthalmology: A pilot program for curricular renewal. Archives of Ophthalmology 117: 1223–1226.

Harden RM, Stevenson M, Downie WW, Wilson GM (1975) Assessment of clinical competence using objective structured examination. British Medical Journal 1: 447–451.

Jones JW, Bieber LL, Echt R, Scheifley V, Ways PO (1984) A problem-based curriculum – ten years of experience. In: Schmidt HG, de Volder ML (eds) Tutorials in problem-based learning. Van Gorcum, Assen/Maastricht, Netherlands.

Kerfoot BP, Masser BA, Hafler JP (2005) Influence of new educational technology on problem-based learning at Harvard Medical School. Medical Education 39(4): 380–387.

Nendaz MR, Tekian A (1999) Assessment in problem-based learning medical schools: A literature review. Teaching and Learning in Medicine 11(4): 232–243.

Nolte J, Eller P, Ringel SP (1988) Shifting toward problem-based learning in a medical school neurobiology course. In: Research in medical education. Proceedings of the twenty-seventh annual conference. Association of American Medical Colleges, Washington, DC, pp. 66–71.

Pawlak SM, Popovich NG, Blank JW, Russell JD (1989) Development and validation of guided design scenarios for problem-solving instruction. American Journal of Pharmaceutical Education 53: 7–16.

Petrusa ER, Blackwell T, Carline J, Ramsey P, McGahie W, Colindres R, Kowlowitz V, Mast T, Soler NA (1991) A multi-institutional trial of an objective structured clinical examination. Teaching and Learning in Medicine 3: 86–94.

Vernon DTA, Blake RL (1993) Does problem-based learning work? A meta-analysis of evaluative research. Academic Medicine 68: 550–563.

Wales CE, Stager R (1972) Design of an educational system. Engineering Education 62: 456–459.

Wood DF (2003) ABC of learning and teaching in medicine: Problem based learning. British Medical Journal 326: 328–330.

Zeitz HJ, Paul H (1993) Facilitator expertise and problem-based learning in PBL and traditional curricula. Academic Medicine 68(3): 203–204.