The Changing Face of Dental Education: The Impact of PBL

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Abstract: The past decade has seen increasing demands for reform of dental education that would produce a graduate better equipped to work in the rapidly changing world of the twenty-first century. Among the most notable curriculum changes implemented in dental schools is a move toward Problem-Based Learning (PBL). PBL, in some form, has been a feature of medical education for several decades, but has only recently been introduced into dental schools. This paper discusses the rationale for the introduction of a PBL pedagogy into dental education, the modalities of PBL being introduced, and the implications of the introduction of PBL into dental schools. Matters related to implementation, faculty development, admissions, and assessment are addressed. Observations derived from a parallel-track dental PBL curriculum at the University of Southern California (USC) are presented and discussed. This program conforms to the Barrows (1998) concept of "authentic PBL" in that the program has no scheduled lectures and maintains a PBL pedagogy for all four years of the curriculum. The USC dental students working in the PBL curriculum have attained a high level of achievement on U.S. National Dental Boards (Part I) examinations, significantly superior to their peers working in a traditional lecture-based curriculum.

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This paper seeks to provide the reader with an overview of the problem-based learning (PBL) process, the present status of PBL in dental education, the modalities of PBL being used, the problems likely to be met in implementing such innovative programs, the human and physical resources required, and some limited data on outcomes from the authors' experience at the University of Southern California (USC) School of Dentistry.[1,2]

PBL Defined

The term "problem-based learning" has been variously interpreted. Many educational programs that profess to employ a PBL pedagogy have doubtful claims in that these programs fail to meet the criteria for authentic PBL programs.[3,4] Barrows,[4] a leader in the field of medical PBL education, refers to "authentic PBL" as addressing three critical educational objectives:

> 1. The acquisition of a rich body of deeply understood knowledge that is integrated from a wide variety of disciplines, structured in ways that will facilitate recall and application to other Problems, and enmeshed with the Problem-solving, required to analyze and solve patient Problems. 2. The development of effective clinical Problem-solving, self-directed learning, and team and interpersonal skills. 3. The development of an insatiable curiosity and a desire to continually learn."

Such a definition appears to be equally applicable to dental as well as to medical education. In any consideration of PBL, it is critical to clarify the difference between "problem-solving exercises," which are frequently and incorrectly reported as being PBL and true (authentic) PBL in the Barrows sense. The difference has been succinctly stated by Inman: "One (problem-solving) leads to a solution but not necessarily to understanding; while the other (PBL) leads to understanding but not necessarily a solution." He continues: "Profound Problem-based Learning may arise from a Problem which has a multiplicity of solutions, or from one which has no solution at all."[5]

Problem-based learning has its origins in health care education in the 1960s at McMaster University in Canada where it was applied in the Medical Sciences curriculum.[6-7] Since that time, PBL has been extensively implemented in medical curricula (and other professional training programs) worldwide, but to only a limited extent in dental education.

In 1984, the dental school at Malmö in Sweden was closed as being in excess of the Swedish national need for dental education. Following the closure of the school, a cohort of the faculty set to work to prepare a completely new curriculum that would be based on the principles of problem-based learning. The faculty were assisted in this endeavor by experts in cognitive learning psychology from European medical schools such as Maastricht University in the Netherlands, which were already using a PBL-based curriculum. In 1990, the Malmö Dental School was reopened with a completely revised dental education curriculum employing a student-centered PBL pedagogy.[8] This development stands as a significant milestone in dental education since, up to that time, problem-based learning had not been significantly employed in dental education. Since that time there has been increasing interest in PBL-based dental curriculum development worldwide. In North America this interest was further promoted by the 1995 Institute of Medicine Report, *Dental Education at the Crossroads*, which strongly urged a reassessment of current dental curricula.[9]

Dental schools currently employing some aspects of PBL in their curricula are found in Europe (Sweden, The Netherlands, Norway, and the United Kingdom); Asia (Hong Kong, Singapore, and Thailand); Australia and New Zealand; and the United States and Canada.

Why PBL in Dentistry?

According to Schmidt, as quoted in Kelly et al.,[10] three conditions that facilitate learning are:

1. Learning has a restructuring character. Earlier knowledge is used in understanding new information.
2. Retrieval cues reactivate information. The closer the resemblance between the situation in which something is learnt and the situation in which it is to be applied, the better the performance and the easier it is in respect of recall and application.
3. Elaboration of knowledge. Information is better understood, processed, and retrieved if students have an opportunity to elaborate on that information. Students can elaborate by answering questions about the matter, by taking notes, by teaching peers what they have already learnt themselves, by summarizing, and by formulating and criticizing hypotheses about a given problem. A teaching-dominated approach fails to accommodate these conditions for learning.

A PBL curriculum, employing student-centered learning, clearly provides conditions that will promote learning based on these three postulates.[11] Among a range of other reasons to convert to a PBL curriculum, we might select:

- Traditional curricula tend to be directed towards memorizing facts and gaining technical skills without sufficient concern for understanding or clinical reasoning.
- Traditional curricula tend to be "dense-packed," allowing insufficient time for reflection and self-directed learning.
- The traditional "pre-clinical/clinical" division of the curriculum inhibits integration and causes students to view the preclinical phase as simply a "hurdle to be overcome."
- In traditional dental curricula, the clinical experience is delayed as a result of the non-integrated course content.
- The scheduling of the subject matter frequently obscures its relevance to clinical situations.
- There may be insufficient emphasis on attributes such as patient/practitioner interactions, communication, and interpersonal and management skills.
- The traditional departmental structure inhibits content integration.
- Traditional curricula fail to emphasize student responsibility for learning. Rather the focus is on faculty responsibility to teach the students.
- Students have historically enjoyed the PBL experience.[12-14]

Modalities of PBL

While PBL has been introduced into the curriculum of a number of dental schools, the mode and degree of the implementation have varied. These different modalities range from the introduction of a single PBL-format course or module to the complete transformation of the curriculum to PBL. Examples of the complete transformation of the curriculum to PBL include the USC parallel track program and the, more recent, University of Hong Kong curriculum.[15]

Perhaps most commonly, PBL dental curricula have been developed as a "horizontal hybrid," essentially preserving the traditional "preclinical/clinical" structure and limiting the PBL component to the first two to three years. While this approach preserves the traditional structure, it suffers from the inability to readily link basic science learning with clinical application, so a degree of vertical integration is lost (see also Houlden[16]). For a fuller discussion of modalities of PBL, see Barrows.[17] In a number of universities, dental schools that are linked with PBL medical schools have chosen to initially place the dental students in the PBL medical curriculum.[18-22] Examples of linkage between medical school PBL and dental education include Harvard, Connecticut, and the University of British Columbia. While this approach has the certain merit of providing the dental student with a firm foundation in medicine, the integration of dentally related case materials may be logistically problematic since the medical faculty directing the sequence and content of the problems may fail to recognize opportunities for linkage to oral signs and symptoms. Finally, in other cases (partial hybrids), PBL implementation has been limited to single courses or curricular "blocks."[23-25] This approach suffers from the drawbacks that integration of curricular content is limited and students are faced with the confusion of drastically contrasted pedagogies (student-centered vs. teacher-centered) within the same time frame. Under such conditions it is likely that students' attention will have a greater focus on the traditional (comfortable) pedagogy, rather than the innovative.[26] (See Table 1 for examples of the different modalities of PBL currently being employed.

PBL vs. "Case-Based" Learning

While PBL employs problem-cases as the focus for promoting student learning, PBL is not the same as "case-based" learning, as is frequently suggested by clinicians: "Oh yes! Of course we use 'cases' in our program." The difference is essentially that outlined by Inman.[5] In case-based learning exercises, the student is usually expected to "solve" the case (i.e., arrive at an acceptable differential diagnosis and treatment plan), applying his or her existing knowledge. In PBL, however, a "case" is employed to prompt the students (as a group) to identify and develop new areas of learning, whether the case is "solved" or not. There is little doubt that PBL develops problem-solving skills in the students, and there is certainly value in providing clinical cases for students to "solve" as a part of formative assessments. At USC, such problem-solving of clinical case data is employed as objective assessment instruments in the third and fourth years of the program. The process of learning in a PBL-based curriculum provides students with the tools to become effective problem solvers, and methods of student assessment should include means to measure this outcome.

PBL: The Process and Effects on Curriculum Change

A PBL pedagogy has three essential components that must be integrated to permit the fostering of an inquiry-driven learning environment. Those components—the problems, the small group learning, and the student-centered environment—must all be present to achieve a successful result (Figure 1). Each of these three components has specific elements that need to be addressed during the implementation of a PBL dental education program. The importance of these three components of PBL can be established in ground rules for the operation of the groups that reinforce the commitment of students, faculty, and curriculum to the PBL ideals (Figure 1).

Table 1. Examples of modalities of PBL currently in use at a selection of dental schools

Modality	Country	School	Class size	Reference
Full implementation	China	Hong Kong	50	15
Full implementation	Ireland	Dublin	~40	10
Full implementation	Sweden	Malmö	40	8
Full implementation	USA	USC	24(140*)	1, 2, 42
Hybrid with Medicine	Canada	UBC	40	20-21
Hybrid with Medicine	USA	Harvard	~40	18-19, 22
Course based hybrid	Australia	Queensland	~50	54
Full implementation	UK	Manchester	65	74
PBL/traditional hybrid	USA	Indiana	100	72

*Scheduled intake for 2001

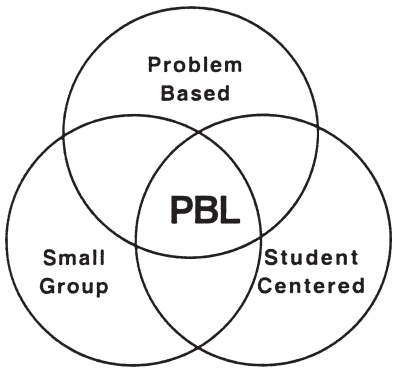
The Problems

A key requirement of a PBL curriculum is that "the problem always comes first." This requirement may be presented as one of the ground rules for the program and has an important meaning for the structure of the curriculum. This ground rule means that all students first encounter a learning objective through the process of discovery in a problem developed by the curriculum organizers and facilitated by a faculty member. This order of introduction requires the student/student group to critically analyze the problem, identify the content needed to understand it, and complete the research necessary to learn the material (Figure 2). It is important that the content is never presented prior to the engagement of the student/student group in the critical thinking required to analyze the problem. Frequently, both students and faculty identify this process as "inefficient" since the perception is that a lecture can more quickly and effectively transmit the material; however, if the students are unprepared intellectually to understand the topic and apply it to a clinical situation, the result will be ineffective transmittal of knowledge. Efficiency in education is an interesting concept that is often perceived to be synonymous with the fewest number of contact hours between faculty and students; yet high efficiency could also be identified as the ability of the student to effectively understand the material and apply it to a clinical situation. Learn-

GROUND RULES FOR PBL GROUPS

Problem-Based-Learning: The "Prime Directives"

I The problem always comes first
II The learning program is student-centered
III Learning takes place within a small group context



A successful PBL program requires that all three of these features are present. Remove any one, and the program fails!

1. **Attendance and punctuality are mandatory.**
2. **Groups must use the wall-charts/boards as they study a case.**
3. **Students should do their thinking aloud in a PBL group.**
4. **Groups must not skip steps in the PBL process.**
5. **Each group must evaluate its process on a regular basis.**
6. **Do not expect your facilitator to provide factual material related to the problem.**

Figure 1. PBL has three essential components. The area of overlap of all three equals effective PBL. The establishment of specific ground rules for the group is an important demonstration of commitment of students, faculty, and curriculum to the PBL ideals.

ing in context through the use of problems to introduce the learning objectives inherently provides for early appreciation of the applicability of the content to patient care. Thus, to have efficient application of material, it is critical that "the problem always come first" and that students understand the importance of the content at the beginning of the learning process.

The use of problems to convey the content of the curriculum through PBL pedagogy requires that the curriculum organizing group first identify the intended outcomes of the program and then establish a sequence of problems that provide the content necessary to achieve the stated objectives. In this regard, the development and sequencing of the problems are critical to provide a comprehensive set of learning outcomes and an orderly progression of the development of competence. In dental education the need to identify graduation competencies and specify the progression during the curriculum towards these competencies provides an important framework for developing and sequencing the problems from which students will learn. Problems must be tested and refined based on the achievement of students. In the event that a problem fails to meet a learning objective intended by the faculty, future problems need to be developed/modified to ensure coverage. While many students and faculty may feel that the PBL curriculum is particularly "unstructured," a large amount of organization is required to structure the sequence of learning and develop a catalog of problems that engage the students' learning in the critical topic areas. Students will "discover" the topics and achieve the desired endpoints, yet frequently remain unaware that their educational progress has been directed by the curricular structure. Student inquiry, inherent in a PBL-based pedagogy, into the nature of the problems will lead them to the underlying structure of the curriculum.

Typical "good" PBL problems have been described as being "real and ill-structured."[27] By this it is meant that the situation/patient case presented by the problem approximates reality and that a full understanding of the problem cannot be achieved without substantial research and learning by the students. The problem should be seen by the students as being relevant to their chosen profession and the real world, thus engaging their interest.

It is essential that each problem be carefully analyzed to define the expected (major and minor) learning objectives it would generate. This factual material is then assembled to from the basis of the curriculum, and the problems can be sequenced appropriately to link with other curricular activities. For example, a problem case dealing with a "patient" who reports with gingival bleeding will generate learning related to gingival histology and aspects of clinical periodontology and an understanding of the fundamental processes of blood clotting. In the experience of the authors, it has proven important to maintain detailed records of all student-generated "learning needs" arising from each problem case. At the completion of each case, the group facilitators are asked to complete a document listing both the "major" and "minor" learning needs identified by the students. These data are entered into a computer database of "Problem Outcomes." Such records support the organization of the curricular content—that is, what material the students will learn and in what sequence that underlies a PBL curriculum.

Case Materials—Sources and Development. While there now exists a substantial pool of developed PBL "cases" for medical education, the same cannot be said for dentistry. In our experience, starting in 1995, no significant body of dentally relevant PBL case materials could be located, beyond the Swedish material and some limited sources in Australia. While modification of existing case materials can generally address the basic biomedical needs of the curriculum, the biodental and clinical case requirements will usually require the creation and testing of new case materials, although a body of dentally related PBL cases is now beginning to emerge (see the International Dental PBL Network, IDPN, and ANZdental web sites which provide links to, and examples of, dentally related PBL case documents[37-38]). Interactions among dental educators throughout the world have begun to develop a significant body of problem material with applicability to dental curricula. These materials have been readily shared, tested in other institutions, and compared as to learning outcomes. As additional institutions move to greater incorporation of PBL, the body of problems available to structure the curriculum is certain to grow.

Among the recommendations of the 1995 Institute of Medicine Report[9] was the recognition that the training of a dental practitioner for the twenty-first century will require that the student initially acquires a substantial body of basic medical knowledge. Noting this requirement, we have found that many existing medical PBL cases that generate learn-

ing needs related to basic biomedical systems can readily be modified to provide a "dental slant" to the case.[1] For example, a medical trauma case, designed to address learning aspects of hematology (hemophilia, clotting cascade, etc.) can easily be modified to make the initial case presentation dental trauma with a problem of prolonged bleeding. Such modifications serve to stimulate dental student interest in a manner that would not usually occur in the "mouthless" medical school environment. A study of the effectiveness of problems has been provided by Dolmans et al.[36]

Small Group Learning

The function of small groups of students together pursuing the problem is a critical element of a PBL curriculum. The literature indicates that groups of about six to eight students is optimal[34], to ensure the participation of all members and to eliminate the segregation of the group into smaller subsets. The function of the group as a learning organization will change over time. In the first semester of a PBL curriculum, it may take as long as two months for a group of students to become highly effective in this type of pedagogy. The change in style of learning, the responsibility to other students in the group, the self and peer evaluations included in the process, and the requirement for student-directed learning will all be new to nearly every entering dental student. The facilitator plays a key role with the new groups to help develop the PBL process of learning and reassure the group that the process is working (Figure 2). The group also provides a critical element of normalizing the learning process, since each member has expectations about the level of accomplishments of the other members. This provides a critical real-time measure of student achievement and prevents members of the group from falling considerably behind. The small group also provides a "safe" learning environment in which students can admit a lack of understanding and receive support and encouragement from their peers, which ultimately leads to the growth of the entire group. A key question often asked of PBL programs regards the nature of remediation of students who fall behind their peers in educational accomplishment. Commonly, remediation occurs through the support of the group, and students are rarely able to fall more than one to two days behind their group without the group intervening to bring all members to a similar level of educational achievement.

A by-product of the small group learning environment is the understanding of functional group dynamics. Most entering dental students have never had to rely on a well-organized group to accomplish an identified goal. Yet in dental practice the function of the group of individuals involved in patient care is essential to ensure the highest quality of oral health care delivery. The skills required to become a well-integrated member of a small group learning environment are critical to the future success of the oral health care professional. The organization of the curriculum again provides a learning objective necessary for the students yet not completely obvious to them as an expected outcome. Each group continually engages in self- and peer evaluation, both to enhance the performance of the group and to begin the development of professional behaviors essential to the successful delivery of oral health care. The format for these self- and peer evaluations has been formalized to assist students in the process and provide facilitators with a reproducible mechanism (Figure 3).

An important aspect of a small group learning environment is student acceptance of this style of pedagogy. Some students may be more comfortable in a traditional learning curriculum, so an element necessary to the implementation of a PBL dental education program is the consideration of the admissions process. We have shown that, by using a less conventional method of dental student admissions, we are able to identify students with a greater potential to excel in a PBL environment.[42]

Admissions in a PBL Curriculum. The PBL process relies heavily on the ability of students to function effectively in a group. A dysfunctional PBL group[39] will result in the failure of some or all of its members to learn. Recognition of this fact requires a reconsideration of the procedures used in admitting students to a PBL program. While the traditional requirement of academic achievement cannot be overlooked, greater emphasis needs to be placed on the selection of individuals who will function effectively in the PBL group. To achieve this, an emphasis may need to be placed on the interview and on identifying individuals who show evidence of working successfully in group situations. An additional factor in selecting students is the recognition that most applicants will have had no prior experience with the PBL process and will need information on the style of this pedagogy. In our experience, much can be gained by organizing applicants into groups and running a short PBL case. Participation of dental school appli-

cants in a real session of PBL learning serves a dual purpose, in that it allows the applicant to experience PBL first hand and it permits faculty to observe applicants in a group situation. Faculty facilitators and observers record subjective assessments for each applicant under the headings of attention, ideas, empathy, comprehension, and language. A further aspect considered important in the application/admissions process is arranging for applicants to observe PBL student groups in session and to discuss the program with current PBL students. The opportunity of the applicants to both participate in an actual PBL learning session and observe the process with current dental students provides all applicants with detailed information concerning this style of learning. Although this process is labor-intensive and time-consuming we believe it greatly assists with the selection of students who will function effectively in a PBL program. These, and related admissions issues have been discussed by Martinez-Burrola et al.[40], Greenwood et al.[41], and by Pereira.[42]

The Student Centered Environment

It should be clear that in any educational program the students are truly the focal point, and all learning methods are thus student-centered. But frequently, this fact is obscured by the delivery of educational content in very traditional ways that are in large part structured to benefit the faculty rather than the student. When classes are designed to tell students at the beginning all the material they must learn and the order in which they must learn it, yet provide little information on the relevance of the material to future career objectives, it becomes difficult to appreciate the "student-centeredness" of the program. Students quickly identify the lowest common denominator for learning, strive to master only the material relevant to exams, and fail to develop high levels of sustainable knowledge. In a truly student-centered environment, faculty recognize the importance of the students in the learning process and understand that the content must be appreciated by the students before they will become motivated to master the material.

The PBL structure inherently recognizes the importance of the student in the process of learning (see Figure 3). The faculty facilitator and the students in the group all develop a level of respect for the thoughts and ideas of others and work to refine and reinforce these thinking processes for their mutual benefit. Importantly, in PBL it is recognized that student research and mastery of material will occur outside the classroom either individually or in subsets of the group. This necessary component of PBL requires that the time in the curriculum reflect this commitment to learning. Thus, sufficient "study time" is required in the weekly schedule, and every effort is needed to prevent erosion of this scheduled time by other activities. Time to learn is a key commitment to a student-centered environment, as well as recognition by both students and faculty that to master the material time is needed. Time is thus an essential structural component of a PBL curriculum.

Structuring the Time Schedule in a PBL Curriculum. Experience with traditional dental or medical curricula suggests that scheduled activities will always expand to fill the time available. Commonly, department chairs will seek additional time in which to teach their "discipline" and will strenuously defend their time against any attrition of their allocations. This condition has been described by Abrahamson as "*Curriculomegaly.*"[35] Among the greater strengths of the PBL pedagogy is its innate ability to integrate the learning of the basic and clinical sciences in a way that transcends traditional departmental boundaries. Thus in a fully implemented PBL curriculum, time is no longer scheduled to departments, but only to "problems." Typically, in the early years, a PBL case may consist of several "parts" provided successively to the student groups; these may occupy student time over a one to two week period. To allow students time for self-motivated independent research and study, it becomes essential to allocate scheduled study time within the weekly schedules. Typically, two to three hours of "scheduled study" time needs to be allotted for each PBL group session.[1] This issue is vitally important for successful PBL outcomes. In curricular structures that employ a hybrid between traditional lecture/lab-based instruction and PBL, scheduled study time is frequently overlooked or negated by pressures from the traditional courses.

PBL in Dental Clinical Education

One comment frequently heard in reviews of PBL for dental education is "PBL works fine for the basic sciences but wouldn't work for the clinical el-

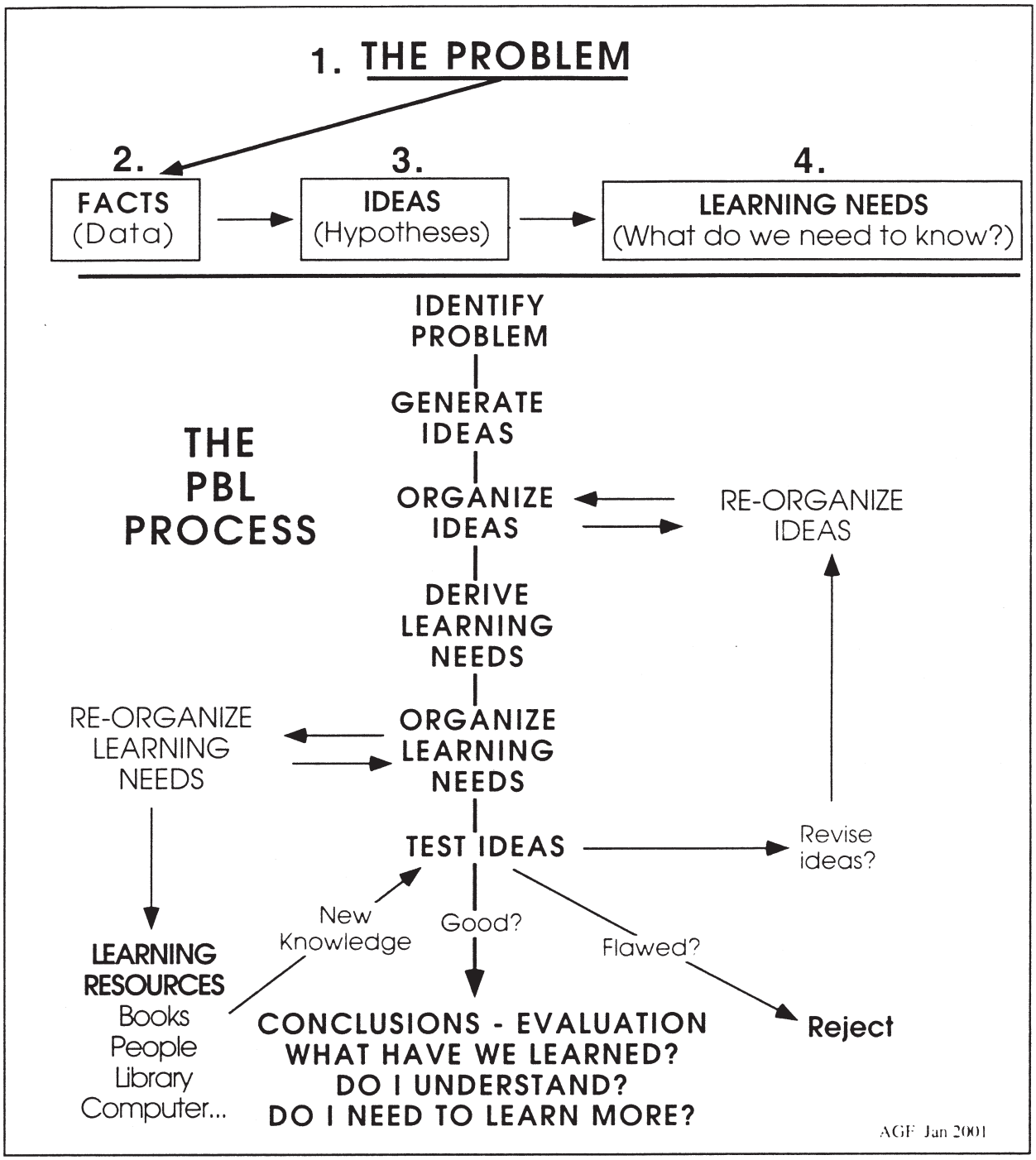


Figure 2. The PBL process: 1) the problem is described; 2) students will identify the relevant "facts"; 3) based on these facts, they will generate a list of "ideas" about the problem; 4) consideration of these ideas will lead to the identification of a list of "learning needs." The lower flow-chart illustrates the iterative nature of the PBL process. As additional data are obtained and facts learned, the ideas are refined and the learning needs revisited.

PBL Process Evaluation – How did I do?

On a scale of a 1-5 score (**1 = Very poor; 5 = Magnificent!**) how do you feel that you have performed in this problem case? (Be objective!)

A. Group skills. I actively participated in the work of the group showing a sensitivity to group needs as well as self needs and demonstrating respect for the aspirations of all members of the group.

B. Learning skills. I effectively identified group and individual learning needs and identified the appropriate learning resources.

C. Reasoning skills. I demonstrated an ability to critically evaluate information, to synthesize and to critically appraise data.

D. Feedback skills. I demonstrated an ability to provide constructive feedback to the group, promoting the group's ability to learn.

AND (One sentence only)

E. I could do better in the following:

F. I feel I did a good job in the following:

G. Overall I would rate our group performance in this case as:

H. In terms of "Interest" I would rate this case as:
(1-5. 1 = Very dull; 5 = Highly interesting)

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Figure 3. Group Self and Peer Assessments

This document is used to assist the facilitator and the group in making an assessment of its work. In practice, at the end of each case, the facilitator asks each student to complete this form. The individual subjective assessments and comments are then tabulated and are discussed with the group. This has been found helpful in prompting the group to consider its collective work and the contributions of each individual. In addition, we have found this process helpful in revealing any interpersonal problems that might be inhibiting the group dynamics.

ements." This type of bias reflects the comments reported by Abrahamson that medical school faculty frequently made that "PBL will work for your students but not for ours." The underlying premise is that the learning of dental clinical procedures is somehow different from other learning, yet there is clearly a cognitive element common to mastering any type of learning content. If the rule that "the problem always comes first" is accepted, then incorporating learning objectives with clinical outcomes would also need to adhere to this rule. Is that possible?

The answer is yes, it is very possible. Problems can be readily developed that introduce any type of clinical learning objective. A simulated patient scenario can be developed that includes the signs and symptoms for any dental patient presentation. The students will direct their learning to understand the pathogenesis of the problem *first,* and then extend the learning process through the stages of diagnosis, therapy, and prevention as directly linked to a particular pathology. Once the pathology is accurately diagnosed by understanding the nature of the signs and symptoms, the basic sciences contributing to the signs and symptoms mastered, and the long-term outcomes of untreated disease understood, the rationale for a particular therapy follows naturally. The problems can easily lead the student to determine the appropriate type of therapy required to eliminate the pathology and restore form and function. Students can explore the principles underlying a particular therapeutic strategy, the materials required, and the steps needed to complete the technique. Thus, the basic learning of the clinical sciences in dentistry can easily be incorporated into a PBL format and student inquiry can be used to lead the process, following the identical pedagogical model used for all other elements of the PBL curriculum. In fact, this type of learning will lead students to develop an evidence base for the methods to diagnose and treat oral disease and allow them to investigate the most recently reported literature—a benefit not often found in clinically related dental courses. Yet, the problem remains that the actual hand skills required to complete the technical procedures, while identified through the PBL format, still need to be practiced and mastered by the student. Again, the comment frequently heard is that these can not be learned in a PBL setting, but is that premise really correct? Is the learning of the hand skills an inherently different cognitive activity that would not be amenable to PBL? Does psychomotor skill development require critical thinking and evaluation?

The development of competency in the procedural skills in dentistry is a requirement for each individual. Similarly the mastery of the cognitive content in the curriculum is the responsibility of each individual student. In PBL, research on learning objectives, mastery of the material, and contact with experts for additional advice are all individual activities that support the objectives of the group. These are similarly supported by members of group providing feedback and reinforcement related to the achievements of the individual. The group evaluation of individual accomplishment provides an important resource for the advancement of both the specific student and the group as a whole. This type of group activity can be similarly applied to the development of competency in procedural skills. The achievement in clinical/preclinical techniques can be viewed as equivalent to the research related to a learning objective and thus a topic for discussion by all members of the group. Self- and peer evaluation of clinical achievements provides a means to integrate procedural skills into a PBL approach using the group as a resource for individual accomplishment. In these ways, the design of the learning environment can be developed to enable a PBL approach to the development of clinical skills.

The organization of PBL for preclinical and clinical technical learning requires that the group structure and learning environment be maintained. At USC, this is accomplished by a small-group, faculty-facilitated "Pre-Session" prior to any preclinical laboratory or clinical activity. In the presessions, students discuss their intended clinical objectives, review the procedures and patients, and establish their readiness to proceed to the "Research Phase" investigating the actual completion of a clinical procedure. The pre-session reviews the delivery of care to either a simulated patient who was the focus for learning in a PBL scenario or a real patient who will be seen in the clinic. In both cases, the completion of specific technical procedures is the focus for discussion and precedes the individual learning experience. The situation is the same both preclinically and clinically, in that all students review their learning objectives and then proceed to the research phase in either the simulator lab or the clinic. In either place, the student-faculty-patient relationship is identical with the current methods of teaching in these environments. Faculty serve as expert resources, mentoring student accomplishment and providing expertise to help students advance their state of knowledge. The

program maintains a database of all student-patient experiences and monitors the accomplishment of each student to ensure the breadth and depth of experience necessary to achieve the curricular competencies. Analysis of the clinical experiences of the first 2 classes to complete the PBL pilot project at USC has shown that the students have a clinical experience level that is within the range for their peers in the traditional track.

The "Research Phase" of PBL in the clinic therefore has a cumulative outcome comparable to that of the traditional track; however, the events before and after the clinical experience are critical to enhance learning. In the research phase, faculty should provide expert information and function as a resource to assist student achievement, exactly as a faculty member would provide expertise when a student researched a problem-generated learning need. In this way, the individual experiences in both the simulator lab and clinic are equivalent to the individual research conducted by students pursuing a PBL problem. The difference is that the outcome is a procedure. However, this procedure represents the outcome of individual research that can be brought to a group for discussion and used to advance the learning of all members of the group. To achieve this end, the research phase is followed by another facilitated small-group "Post-Session" in which the student group discusses the outcomes, identifies deficiencies, and establishes additional didactic learning and technical practice needed to advance their level of accomplishment. This cycle of learning is exactly the PBL model and provides the students with critical peer support for the learning and application process and a method of self- and peer evaluation. In all of these instances, every student in the group learns from all the other students and consequently expands his or her range of experience far beyond individual activity. The small groups provide an excellent opportunity to reinforce clinical guidelines and standards and to normalize the accomplishment of the groups.

A key element in the use of PBL in the clinical areas is to establish the sequential clinical achievements for the student groups. As in a medical residency, the group of students can be linked to particular levels of clinical competency, and the learning objectives in the problems can be established to achieve this competency (Table 2). At USC, we have established a sequence of clinical skill sets that gradually introduces the student to patient care. The development of clinical skills has been sequenced so that students in all four years of the curriculum can be involved in the comprehensive care of patients. Verticalized treatment teams are organized with one student from each of the first-, second-, third-, and fourth-year classes. Each of the teams has a practice with patients whose comprehensive care is their responsibility. All of these students in the vertical team participate in evaluating patient needs and developing a comprehensive treatment plan. The fourth-year student has the role similar to a senior resident in a medical residency, with the supervising faculty serving as the attending doctor. Once a treatment plan is established for a patient, individual students provide care at the level of their clinical competency with frequent interaction and collaboration with all student members of the team. This situation models the methods used in medical residency because it involves all levels of experience in the care of patients and allows each member of the team to provide care at the level of their competence. The structure also provides a means for all students to reach their eventual educational goal and to benefit from an increased number of patient care experiences. The integration of all levels of student skill into the treatment of patients provides both high-quality comprehensive care and the opportunity for all students to participate in a greater number of clinical experiences to broaden the educational experience. The inclusion of a presession and post-session format permits the PBL pedagogy to be perpetuated in the clinical situation and reinforces the commitment of the dental education program to a consistent method to enhance student learning.

Introducing PBL into the Dental School

In the introduction, we referred to the Malmö University Dental School, where a PBL curriculum was introduced when the school was reopened. This situation is reminiscent of the original introduction of PBL in 1965 at McMaster University Health Sci-

Table 2. Clinical skill progression in a PBL curriculum

Year	Skill Set
1	Dental Hygiene
2	Single tooth, single tissue therapies
3	Multiple teeth, multiple tissue therapies
4	Comprehensive care using all clinical abilities

ences, where PBL was adopted as the pedagogy for an entirely new medical education program.[6] In both of these cases, one dental and the other medical, an innovative PBL-based curriculum was developed and implemented in a new school, allowing the innovators a free rein unlikely to occur when the traditional curriculum of an existent school is being converted to PBL.

The process of changing a traditional dental/medical curriculum to PBL cannot be taken lightly,[28-30] since the changes involved are not a simple "tweaking" of existing courses or blocks. Rather, the conversion involves the total transformation of the social and academic structure of the school in a manner likely to engender both skepticism and hostility among some faculty. These problems have been addressed by Abrahamson.[31] Experiences at Harvard and at the University of Hawaii have been recorded by Moore[22] and Anderson.[32] One approach to the introduction of a PBL curriculum is the initial introduction of a "pilot" program,[33] or "parallel track" program, as was initiated at University of Southern California[1-2] in 1995. The introduction of a PBL pedagogy requires the completion of several essential events to prepare both the dental faculty and the school facility for the optimal environment for the pedagogy.

Faculty Development

Among the many changes required to convert a traditional dental education curriculum to PBL, none is more important than that of faculty development. In a PBL curriculum, the role of the faculty member is changed so radically that a high degree of discomfort, if not direct opposition, must be expected. It becomes critical for the innovators to work together with "traditional" faculty to develop a collective understanding of the philosophy of the PBL pedagogy and its relationship to cognitive psychology principles. Further, faculty have to be helped to adapt from their traditional roles of "teacher/instructor" to that of a "facilitator" of learning for student groups. For some, such a change in professional role and behavior may prove to be unacceptable; but many will come to find their involvement in the more closely personal role of group facilitator rewarding. In a PBL curriculum, the faculty facilitator works directly with the group to explore the problem, extract the relevant facts, generate hypotheses and, finally, identify the learning needs the students will need to research in order to better evaluate their hypotheses. In all of this, the facilitator does not act as a teacher or as a "content expert," but seeks to help the group work with the problem ("case") to gain maximum benefit from their learning. This is a demanding new role for many faculty and will require both prior learning, sensitization, and practice before the satisfaction of proficiency will be achieved. A variety of published guides, courses, and on-line resources exist to assist in this development process, [43-48] but hands-on guidance from local experienced facilitators and educators is likely to be needed.

The training and development of a cadre of effective PBL facilitators (called "Tutors") is a critical step in any implementation of PBL. Generally, only a few faculty are likely to have well-developed facilitator skills and experience. Our experience at USC has shown that initially the majority of novice facilitators will adopt one of two patterns: either becoming essentially mute, having a minimal involvement in the activities of the group beyond supplying the necessary problem documents, or adopting a highly directive role in which they seek to control all aspects of the groups' work and push the student group towards specific learning objectives. This latter behavior pattern is especially prevalent in faculty who may have content expertise in an aspect of the subject matter of the problem.[49-54] It is, however, useful to reflect that, in a fully implemented PBL curriculum, the scope of the student-generated learning arising from any particular "case," will often exceed the "expert knowledge" of the facilitator. Observation of sessions with experienced facilitators and subsequent discussion is a critical learning experience that needs to be followed by peer mentoring when new facilitators begin their first case. Systems can be developed to videotape and observe small group sessions and provide data that can be used to improve both facilitation skills and group dynamics.

Faculty academic and professional expertise also becomes a critical resource for student accomplishment. The ability of faculty experts to bring together lines of thought and integrate critical information is a vital resource for any PBL curriculum, which emphasizes a future role for current expert faculty.

Physical Resources—Space

A further and potentially costly issue in conversion to PBL is the need to modify existing space to meet the needs of PBL student groups. Effective

PBL groups comprise from five to eight students working with a faculty facilitator. Thus, a PBL curriculum requires that a suitable number of smaller rooms are available to accommodate these groups that are at the heart of the PBL process. While traditional dental and medical school buildings usually have available a selection of "seminar" rooms, it is likely that these alone will be inadequate to meet the needs of a fully integrated PBL curriculum. Most schools have large lecture theaters that are appropriate for large group presentations but not of great utility for most aspects of a PBL curriculum. Structural modifications are likely to be required, probably at the expense of lecture theatre space. The small rooms Ialso need internet connections and equipment to support the activities both of the group process and the student learning needs completion.

Learning Resources—Libraries

A critical item in an effective transition to a dental PBL curriculum, is the availability of "learning resources" appropriate for the student research arising from PBL cases. As noted above, in the earlier stages of the curriculum there is likely to be an emphasis on learning biomedical sciences; depending on class size, this may put stress on the more traditional dental school library resources. If students have ready access to a medical school library, then this difficulty can be, at least partially, ameliorated. However, it is a general observation that PBL students will make far greater demands on library resources than their traditional peers, so it becomes important to involve the librarians in the conversion to the PBL curriculum.[55-57] Beyond the library resources, thought needs to be given to the accessibility to computer (Internet) resources, clinical simulators, etc., for the demands on those resources may change with curricular conversion.

Assessment in a Dental PBL Program

In a problem-based learning curriculum, assessments are used in two ways. One is to inform students of their progress, so that they can practice self-directed learning more effectively. The other is to test the students' progress in the acquisition and assimilation of knowledge and skills. However, in the early stages of the program it is useful to also assess the students' abilities in the PBL process. The methods of assessment are critical for the reinforcement of program objectives. If the methods of student assessment do not mirror stated program objectives, the students will eventually make "strategic" learning decisions that address the assessment methods they encounter. In PBL, it becomes critical to develop assessment methods that measure student achievement in the process of problem dissection, identification of learning objectives, and development of critical thinking skills. As students achieve these outcomes, the assessment methods need to reflect the application of these skills in problem-solving situations, so that the development of the desired educational objectives can be measured. Subjective assessments can be made on a continuous basis by faculty group facilitators and through self- and peer assessments at the end of each case. A further subjective assessment instrument is the "Triple Jump" exercise,[58] in which students are required to work through a problem case individully, and assessment is based on their self-directed learning skills. Both the group evaluations and the triple jumps measure the development of students' critical thinking skills and application of the learning process. Beyond these assessments of the PBL process, more traditional objective outcome-oriented assessments may include problem-solving exercises, multiple-choice tests to assess levels of factual recall, objective structured clinical examinations (OSCE), and clinical competency assessments. Reviews of assessment methods in a PBL curriculum have been provided by O'Neill,[59] Swanson et al.,[60] Sullivan,[61] and Chaves et al.[62] All of the assessment methods used need to be integrated, so that all of the educational objectives are achieved by specific outcome measures.

Outcomes and the Way Forward

Outcomes data for educational programs may be thought of under several headings, such as clinical competency, performance in national or local professional examinations, and long-range behavioral characteristics of the graduates. Blake et al.,[63] provide a discussion of the twenty-five-year experience in student evaluation methods at McMaster Health Sciences, and while concluding that "Problem-based learning in small groups have *(sic)* stood the test of time," they also acknowledge that "We have not yet arrived at a perfect system."

In an earlier study of PBL outcomes at nineteen institutions, Vernon and Blake[64] conclude that "results support the superiority of the PBL approach over more traditional methods." These reports relate to medical education, but when we turn to dental education the record is mostly too new to derive broad data on outcomes, comparable to those from medicine. The dental school at Malmö has graduated five classes of students (200 graduates) and appears satisfied with the outcomes observed.[8] Others[65-70] have reported and discussed outcomes from PBL programs and courses. Greenwood et al.,[71] compared the perceptions of competency of dental graduates from a traditional curriculum to those graduating from a PBL curriculum and concluded that the self-perceived levels of competence were comparable. Seeking an independent objective external assessment instrument, we reported[2] on the results obtained by the first class of USCSD PBL-track students (n=12) on the Part I National Dental Board Examination and demonstrated a significantly superior performance of the PBL students, at all subject levels, as compared both with their peers in the USCSD traditional track and with national means. It is noteworthy that this was achieved by dental students working in a fully implemented "authentic"[4] PBL program in which learning occurred almost solely through the medium of scheduled biomedical/biodental case simulations. Some preparation for the board examinations is undoubtedly obtained through the ongoing (twice per semester) objective multiple choice question (MCQ) assessments that examine recall of material related to the PBL cases. At USC, these assessments usually employ "board-type" questions. Further, as noted previously[2,42] a demographic comparison of the USC PBL-track students and their peers in the traditional track showed no significant differences between the two groups.[2]

At USC, forty-eight students in the PBL track (Classes of 1999 to 2002) have now sat the National Dental Boards Part I examination. An analysis of the scores obtained by these students, as compared with those obtained by their peers in the USC traditional track (481 students), shows that the mean average score of PBL students is 88.7 as compared to a mean average of 83.4 for the traditional students. An independent t-test shows that the mean difference between these two groups of students is statistically significant (t=-6.5, p=.000). Further, this significant difference is also shown in all the mean scores for all four of the sub-tests of the Part I board examination (Anatomical Sciences, Biochemistry/Physiology, Microbiology/Pathology, and Dental Anatomy). Based upon this experience, we conclude that dental students working in an authentic PBL program, in which there are no scheduled lecture presentations, exhibited a high level of achievement in a standardized external assessment (National Dental Boards, Part I) that was equal, if not superior to the majority of U.S. dental school students working in a traditional lecture-based didactic curriculum.[2,75]

In conclusion, we summarize our findings as follows:

- PBL has been implemented in dental schools worldwide over the past decade, and this trend appears to be increasing.
- Dental schools considering moving to PBL should be mindful of the changes required in physical plant and infrastructure and of the implications for faculty development, new curriculum materials, and student admissions procedures.
- Experience with the USC parallel-track PBL program has demonstrated the feasibility of implementing a PBL pedagogy across all years of the curriculum, fully integrating basic and clinical science learning.
- Student achievement at the level of scores in the U.S. National Dental Boards (Part I) has been found to be significantly higher for USC PBL students as compared to either their peers in a traditional curriculum or to national means.

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REFERENCES

1. Fincham AG, Baehner R, Chai Y, et al. Problem-based learning at the University of Southern California School of Dentistry. J Dent Educ 1997;61:417-25.
2. Shuler CF, Fincham AG. Comparative achievement on National Dental Board Examination Part I between dental students in problem-based learning and traditional educational tracks. J Dent Educ 1998;62:666-70.

3. Maudsley G. Do we all mean the same thing by "problem-based learning"? a review of the concepts and a formulation of the ground rules. Acad Med 1999;74:178-85.
4. Barrows HS. The essentials of problem-based learning. J Dent Educ 1998;62:630-3.
5. Inman D. "So by false learning is good sense defac'd": Can the academy tolerate a new methodological orthodoxy? Address, McMaster University. 1994.
6. Neufeld V, Barrows H. The McMaster philosophy: an approach to medical education. J Med Educ 1974;49:1040-50.
7. Barrows HS, Tamblyn RM. Problem-based learning: an approach to medical education. New York: Springer, 1980.
8. Rohlin M, Petersson K, Svensater G. The Malmö model: a problem-based learning curriculum in undergraduate dental education. Europ J Dent Educ 1998;2:103-14.
9. Field MJ, ed. Dental education at the crossroads. Washington, DC: National Academy Press, 1995.
10. Kelly M, Shanley DB, McCartan B, et al. Curricular adaptations towards Problem-based learning in dental education. Europ J Dent Educ 1997;1:108-13.
11. Norman GR, Schmidt HG. The psychological basis of problem-based learning: a review of the evidence. Acad Med 1992;67:557-65.
12. Kaufman DM, Mann KV. Comparing students' attitudes in problem-based and conventional curricula. Acad Med 1996;71:1096-9.
13. Lancaster CJ, Bradley E, Smith IK, et al. The effect of PBL on students' perceptions of learning environment. Acad Med 1997;72:S10-S12.
14. Pau AK, Collinson S, Croucher R. Dental students' evaluation of 2 community-oriented PBL modules. Europ J Dent Educ 1999;3:159-66.
15. University of Hong Kong, School of Dentistry, Curriculum: www.hku.hk/dental/english/undergraduate/index.html.
16. Houlden RL, Collier CP, Frid PJ, et al. Problems identified by tutors in a hybrid problem-based learning curriculum. Acad Med 2001;76:81.
17. Barrows HS. A taxonomy of problem-based learning methods. Med Educ 1986;20:481-6.
18. Matlin KS, Libert E, McArdle PJ, et al. Implementing the problem-based curriculum at Harvard School of Dental Medicine. J Dent Educ 1998;62:693-708.
19. Howell TH, Matlin K. Damn the torpedoes—innovations for the future: the new curriculum at the Harvard School of Dental Medicine. J Dent Educ 1995;59:893-8.
20. Clark CD, Harrison RL, MacNeil MAJ, et al. The new dental curriculum at the University of British Columbia: integrating with medicine. J Dent Educ 1998;62:718-22.
21. MacNeil MAJ, Walton JN, Clark CD, et al. Structuring a clinical learning environment for a hybrid-PBL dental curriculum. J Dent Educ 1998;62:723-8.
22. Moore GT. Initiating problem-based learning at Harvard Medical School. In: Boud D, Feletti G., eds. The challenge of problem-based learning, 2nd ed. London: Kogan Page, 1997:73-80.
23. Bell FA, Hendricson WD. A problem-based course in dental implantology. J Dent Educ 1993;57:687-95.
24. Forrest AS, Walsh LJ, Isaacs G, et al. PBL as a tool for integrating anatomy into the dental curriculum. J Dent Educ 1998;62:685-92.
25. Walton JN, MacNeil MAJ, Harrison RL, et al. The integration of psychomotor skills in a hybrid-PBL dental curriculum: the clinical clerkships. J Dent Educ 1998;62:729-32.
26. Woods DR. Issues in implementation in an otherwise conventional programme. In: Boud D, Feletti G., eds. The challenge of problem-based learning, 2nd ed. London: Kogan Page, 1997, 173-80.
27. Westberg J, Jason H. Fostering learning in small groups. New York: Springer, 1996.
28. Lim LP, Chen AY. Challenges and relevance of problem-based learning in dental education. Europ J Dent Educ 1999;3:20-6.
29. Aldred SE, Aldred MJ, Walsh LJ, et al. Implementing problem-based learning into professional and dental education. J Dent Educ 1998;62:644-9.
30. Bernstein P, Tipping J, Bercovitz K, et al. Shifting students and faculty to a PBL curriculum: attitudes changed and lessons learned. Acad Med 1995;70:245-7.
31. Abrahamson S. Obstacles to establishing problem-based learning. J Dent Educ 1998;62:656-9.
32. Anderson AS. Conversion to Problem-based learning in 15 months. In: Boud D, Feletti G., eds. The challenge of problem-based learning, 2nd ed. London: Kogan Page, 1997;64-72.
33. Vincelette J, Lalande R, Delorme P, et al. A pilot course as a model for implementing a PBL curriculum. Acad Med 1997;72:698-701.
34. Lucero SM, Jackson R, Galey WR. Groups in problem-based learning. In: Kaufman A, ed. Implementing problem-based medical education. New York: Springer, 1985:45-70.
35. Abrahamson S. Diseases of the curriculum. J Med Educ 1978;53:951-7.
36. Dolmans DH, Gijselaers WH, Schmidt HG, et al. Problem effectiveness in a course using problem-based learning. Acad Med 1993;68:207-13.
37. International Dental Problem-based Learning Network site: www.usc.edu/hsc/dental/ccmb/IDPN/PBLdental_site1.htm.
38. Australian and New Zealand Dental Education Network for Teaching and Learning (ANZDental site): members.nbci.com/anzdental/.
39. Hitchcock MA, Anderson AS. Dealing with dysfunctional tutorial groups. Teach Learn Med 1997;9:19-24.
40. Martinez-Burrola N, Klepper DJ, Kaufman A. Admissions in a problem-based curriculum. In: Kaufman A ed. Implementing problem-based medical education. New York: Springer 1985:164-79.
41. Greenwood F, Townsend G, Joseph V, Wetherell J. Introducing Adelaide dental students to a problem-based learning curriculum. Europ J Dent Educ 1999;3:15-9.
42. Pereira LS. Admission processes in the dental PBL at USC. J Dent Educ 1998;62:680-4.
43. Kanter SL. Fundamental concepts of problem-based learning for the new facilitator. Bull Med Lib Assoc 1998;86:391-395.
44. Des Marchais JE, Chaput M. A comprehensive continuous preclinical PBL tutor training system. Teach Learn Med 1997;9:66-72.

45. Tipping J, Freeman RF, Rachlis AR. Using faculty and student perceptions of group dynamics to develop recommendations for PBL training. Acad Med 1995;70:1050-52.
46. Branda LA, Sciarra AF. Faculty development of problem-based learning. Ann Commun Orient Educ 1995;8:195-208.
47. Kaufman DM, Holmes DB. Tutoring in problem-based learning: perceptions of teachers and students. Med Educ 1996;30:371-7.
48. Nayer M. Faculty development for problem-based learning programs. Teach Learn Med 1995;7:138-48.
49. Dolmans DH, Wolfhagen IH, Schmidt HG. Effects of tutor expertise on student performance in relation to prior knowledge and level of curricular structure. Acad Med 1996;71:1008-11.
50. Silver M, Wilkerson L. Effects of tutors with subject expertise on the problem-based tutorial process. Acad Med 1991;66:298-300.
51. Hay PJ, Katsikitis M. The 'expert' in problem-based and case-based learning: necessary or not? Med Educ 2001;35:22-6.
52. Kaufman DM, Holmes DB. The relationship of tutors' content expertise to interventions and perceptions in a PBL medical curriculum. Med Educ 1998;32:255-61.
53. Regehr G, Martin J, Hutchinson C, et al. The effect of tutors' content expertise on student learning, group process and participant satisfaction in a problem-based learning curriculum. Teach Learn Med 1995;7:225-32.
54. Walsh LJ, Seymour GJ, Forrest AS, et al. Differing roles of the tutor in problem-based learning: the Queensland experience. J Dent Educ 1998;62:634-9.
55. Saunders K, Northup DE, Mennin SP. The library in a problem-based curriculum. In: Kaufman A, ed. Implementing problem-based medical education. New York: Springer, 1985:71-88.
56. Schilling K, Ginn DS, Mickelson P, et al. Integration of information-seeking skills and activities into a problem-based curriculum. Bull Med Lib Assoc 1995;83:176-83.
57. Lewis M. Library requirements and problem-based learning: the medical sciences library, the University of the West Indies. Bull Med Lib Assoc 2000;88:255-7.
58. Painvin C, Neufeld V, Norman G, et al. The "triple jump" exercise—a structured measure of problem solving and self directed learning. Proc Ann Conf Res Med Educ 1979;18:73-7.
59. O'Neill PN. Assessment of students in a problem-based learning curriculum. J Dent Educ 1998;62:640-3.
60. Swanson DB, Case SM, van der Vleuten. Strategies for student assessment. In: Boud D, Feletti G, eds. The challenge of problem-based learning, 2nd ed. London: Kogan Page, 1997:269-282.
61. Sullivan ME, Hitchcock MA, Dunnington GL. Peer and self assessment during problem-based tutorials. Americ J Surg 1999;177:266-9.
62. Chaves JF, Chaves JA, Lantz MS. The PBL-Evaluator: a Web-based tool for assessment in tutorials. J Dent Educ 1998;62:671-4.
63. Blake JM, Norman GR, Smith EKM. Report card from McMaster: student evaluation at a problem-based medical school. Lancet 1995;345:899-902.
64. Vernon DTA, Blake RL. Does problem-based learning work? a meta-analysis of evaluative research. Acad Med 1993;68:550-63.
65. Kaufman DM, Mann KV. Comparing achievement on the Medical Council of Canada Qualifying Examination Part I of students in conventional and problem-based learning curricula. Acad Med 1998;73:1211-3.
66. Login GR, Ransil BJ, Meyer M, et al. Assessment of preclinical problem-based learning versus lecture-based learning. J Dent Educ 1997;61:473-9.
67. Walton JN, Clark DC, Glick N. An outcomes assessment of a hybrid-PBL course in treatment planning. J Dent Educ 1997;61:361-7.
68. Thomas RE. Problem-based learning: measurable outcomes. Med Educ 1997;31:320-9.
69. Colliver JA. Effectiveness of problem-based learning curricula: research and theory. Acad Med 2000;75:259-66.
70. Kaufman DM, Mann KV. Evaluating problem-based learning. Acad Med 1996;71:S52-S54.
71. Greenwood LF, Townsend GC, Wetherell JD, et al. Self-perceived competency at graduation: a comparison of dental graduates from the Adelaide PBL curriculum and the Toronto traditional curriculum. Europ J Dent Educ 1999;3:153-8.
72. Lantz MS, Chaves JR. Implementing a new predoctoral curriculum with a PBL component at Indiana University School of Dentistry. J Dent Educ 1998;62:675-9.
73. University of Liverpool School of Dentistry: www.liv.ac.uk/~luds/.
74. University of Manchester School of Dentistry: www.den.man.ac.uk/Applications/undergrad.htm.
75. Wang HS, Fincham AG, Shuler CF. Achievements of dental students in an "authentic" PBL curriculum: a four year study. Unpublished manuscript.