PBL: An Evaluation of the Effectiveness of AUTHENTIC PROBLEM-BASED LEARNING (aPBL)

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The acronym PBL has been used to describe a wide range of different educational interventions. At one end of the spectrum is the original or authentic version developed at McMaster University medical school in the 1960s,[1] which Barrows[2, 3] called aPBL. Barrows[4] distinguishes among some of the different versions of what one might refer to as "problem-based learning" based on 1) the outcomes, 2) the style of the problem presentation, and 3) the interaction and responsibilities of the teacher and the students. The outcomes he lists are: learning and using new knowledge, structuring the knowledge for use in future professional contexts, increased motivation for learning, and developing effective reasoning, problem-solving skills with the guidance of the tutor, team skills, skills in self-assessment, lifelong learning skills, and teaching skills. In aPBL the focus is on empowering the students with the learning process. Given a problem, students realize they don't know key knowledge, they contract with each other that different team members will learn new knowledge and return to the group and teach all the members the new knowledge. This medical school approach empowers the student with the learning process and has the following attributes:[1, 3, 5-7] small group (4 to 8 students), self-directed, self-assessed, interdependent problem-based learning. Self-directed means that, for the professionally significant problem, the students decide what they know already, what they need to know, receive approval from the tutor that their learning objectives are appropriate, contract with each other, research and prepare teach notes, teach, and assess the knowledge learned and problem solved. The faculty do not lecture; faculty are tutors. All students are responsible for learning all the new knowledge. aPBL is used for two different outcomes that Schmidt et al.[7] calls Type I and Type II. The outcome for Type I aPBL is knowledge acquisition. For Type II, the outcomes are acquisition of both knowledge and clinical skills.[8, 9]

At the other end of the spectrum is problem-based synthesis, sometimes called project-based learning. In this model students are asked to use previously learned knowledge to solve a problem. Samson University[10] uses a variation of problem-based synthesis where a problem is posed, the teacher lectures on the knowledge needed and then the students apply the knowledge. In this option, faculty lecture to set the context, and supply information and background material.[10] Versions of this lecture-style problem-/project-based learning are described by Kolmos et al.[11] Design projects are another example of problem-based synthesis. Here the students have already learned the fundamentals needed to solve the project. If the students need to learn additional knowledge to solve the project, they usually divvy up the parts of the project. Each learns the new knowledge needed to solve his/her part of the project. The other

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To evaluate the effectiveness of any learning environment, for clarity, we must study comparable educational interventions. Hence, articles describing learning that the authors call PBL but from their description are using problem-based synthesis, hybrid PBL, problem-assisted learning or project-based learning are not included in this analysis.

With a focus on aPBL, and this form alone, we review the literature in engineering and medical fields of the effectiveness of aPBL.

EFFECTIVENESS

The effectiveness of aPBL, compared to traditional lectures, has been reported for 12 claims. Some researchers used measures of performance; others used questionnaires about perceptions.

Comparable subject knowledge acquisition. Performance on exams has been used to determine differences in knowledge acquisition between students in aPBL and in conventional lecture-style instruction. Some of the earlier analyses of aPBL reported that marks in the subject knowledge of medical doctors, MDs, on the National Board Medical Examiners I, NBME I, (which tests factual knowledge) were statistically significantly lower than marks obtained by MDs from the traditional programs.[14, 15] Dochy et al.,[6] however, recently reconsidered that research in the medical area, and added more recent studies. They concluded that the marks by students in the aPBL programs were as good if not better, but not significantly so, than those obtained by graduates of the conventional programs. Schmidt et al.[7] in medicine, Mehta,[16] in a Mechanical Measurements course, and Mantri et al.,[17] for an externally set subject knowledge exam in a course in digital electronics, found no significant difference between marks of aPBL students and students in traditional courses. Mantri et al.[17] found that aPBL marks on internally set subject knowledge exams were statistically significantly better than traditionally educated students.

Improved clinical or troubleshooting skills. For Type II aPBL, clinical skills for graduates of the aPBL program were statistically superior to those graduating from the conventional program as measured by graduate's performance on four measures: NBME II, cases, simulations, and Modified Essay Questions.[6, 14, 15] For engineering students the skill is troubleshooting. Mantri et al.[17] found that the aPBL marks on a troubleshooting task on a circuit were statistically significantly better than lecture-based. In summary, for Type II aPBL where clinical skill development was explicitly built into the experience, statistically significant performance occurred.

Deep learning instead of surface learning. Students have preferred styles of learning. Deep learners search for meaning in what they are learning. Surface or rote learners ask "tell me what to learn and I'll learn it." Strategic learners will adapt their style of learning to the expectations of the course. Students who are given lectures throughout their college years show an increase in surface learning. They may enter universities with a preference for deep learning but that preference decreases and surface learning increases attributed mainly to their lecture experience. On the other hand, students experiencing aPBL show the opposite. Their initial use of surface learning decreases and their use of deep learning increases.[18-21] Indeed, there is a statistically significant increase in deep learning as measured by pre- and post tests using the Lancaster Approaches to Studying Questionnaire.[20-24]

High-quality learning environment. Ramsden and Enwistle[23] found the key factors in learning environments that promote deep instead of rote learning include good teaching, openness to students, the clarity of the goals and assessment, student's freedom in learning, the vocational relevance of the course, and the social climate. The negative factors are the workload and the degree of formal didactic lectures. These factors are used in the Course Perceptions Questionnaire, CPQ,[21-24] or sometimes called the Course Experience Questionnaire. The CPQ has been used as input for funding decisions by Higher Education Funding Agencies in Australia since the mid-1980s.[25, 26] For conventional lectures, the CPQ is about 18 to 23 with student/control-centred ratio < 1. For aPBL, CPQ values are usually between 30 and 45 with student/control-centred ratio > 1 (often 2 to 4).[23] A perception survey of over 20,000 Dutch students showed that aPBL students rated the quality of the learning environment superior especially in providing independent study, critical thinking, coherence of content, and preparation for the profession.[7] In aPBL the students feel more supported, less stress, and less alienation than students in conventional programs.[7]

Knowledge retention higher. We want our graduates to retain the knowledge they learn. Long term (2- to 4-year) knowledge retention was statistically significantly higher from students in aPBL programs compared with those from conventional program.[6, 7, 27, 29-32] Martenson et al.[29] reported 60% higher long-term retention after 2 to 4 1/2 years for graduates from aPBL over graduates from conventional MD programs. The aPBL students recalled five times more concepts than did students in conventional programs.[30] Confirming evidence from other researchers is summarized by Norman and Schmidt[31] and by Hung, Jonassen, and Liu.[32]

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In aPBL the focus is on empowering the students with the learning process. Given a problem, students realize they don't know key knowledge, they contract with each other that different team members will learn new knowledge and return to the group and teach all the members the new knowledge.

For the retention of skills acquired, first-year students at The University of Guelph[10] experienced a course run as aPBL, seminar, or lecture. In their third year, students from aPBL and the seminar course completed questionnaires about their skills that they retained. Those from aPBL rated their skills to be far superior, compared with those who had experienced the seminar-style course. A statistical analysis was not done.

Motivation higher. Student motivation, as measured by student response to learning environments, was statistically significantly higher for students in the aPBL program compared with those in conventional programs.[27,33]

Exit surveys and alumni: positive. Surveys and written feedback from graduates, alumni, and employers provide softer, yet nevertheless useful evidence. One useful survey has been the Queen's University's Exit Survey.[24,35] On this survey, students from McMaster's Chemical Engineering problem-solving-aPBL program rated problem solving, communication, and critical thinking as important skills that were developed in our program. Regrettably, life-long learning was not included in the original Queen's exit survey. McMaster also developed its own survey asking graduates to identify the most useful experience or courses. The results were that 58% identified the problem-solving aPBL sequence of courses as contributing to their career success.[34] Other courses or experiences cited were 25% "engineering fundamentals" and 10% project work.

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In summary, evidence about the effectiveness of aPBL, compared with traditional lectures, was listed. Now consider the issues and steps to be addressed to implement aPBL.

IMPLEMENTING aPBL

The ABET accreditation criteria introduced in 2000 list 11 Criterion 3 outcomes for engineering programs.[40] Felder and Brent[41] suggest that "the instructional method known as problem-based learning (PBL) can easily be adapted to address all 11 outcomes of Criterion 3. Once problem-based learning has been adopted in a course, very little additional members of the team rarely learn the knowledge acquired by the other members of the team, however. "Project-based must not be confused with problem-based. The former is designed to reinforce what has already been taught and demonstrate the relevance of knowledge. PBL (problem-based learning) poses a problem that is set before the knowledge has been acquired, and the problem causes the students to acquire the knowledge they need to complete the task."[12] Mills and Treagust[13] also distinguish between problem-based and project-based experiences. The outcomes, the knowledge learned and the overall learning experience are different.

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In 1982 the McMaster Chemical Engineering Department implemented aPBL via tutorless, autonomous groups in the context of classes with 30 to 70 students and one instructor. To prepare students for aPBL, in the sophomore year they had one required, workshop-style course to develop the students' skill and confidence in those prerequisite skills needed for tutorless groups. Two required courses in the junior year developed more required skills. Then aPBL was used in one senior course that included engineering economics. The knowledge learned included interest and depreciation, investment, money flow in a company, financial attractiveness and capital and operating cost estimation. Typically we formerly used four weeks of lectures/tutorials to "cover" this material. We replaced the lecture class time with aPBL and considered one case each week. In addition to the students' self-assessment of the subject knowledge gained, faculty judged the students' performance on written exams on this topic to be as good as previous years when they "learned" the material from conventional lectures, although we did not do a rigorous statistical analysis. An alumni survey praised this approach and neither alumni nor employers suggested any deficiency in subject knowledge.[20,34] The student response was so positive to this way of learning, that, at their insistence, we replaced three weeks of traditional lectures with aPBL in a junior-level course on safety and process analysis. Details are available.[20,42-49] Based on this experience, plus that gained from giving numerous workshops on aPBL in different cultures, contexts, and subjects (English, Geography, Civil Engineering, Policing, Nursing) here are the initial implementation issue to address and the seven key decisions to make.

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1. Initial Decision: Tutored or tutorless Groups

A major initial issue is tutored vs. tutorless groups.[48] In my experience, if there is one instructor and a class of more than 20, then tutorless groups is the preferred option.[43,5] If the whole department or program is going aPBL, so that one faculty member can be a tutor for each group of five to eight students, then tutored aPBL is probably the best choice.[48] This tutored approach is described most extensively by Barrows[1,3] and Schmidt.[7,31,36,37] An intermediate approach uses one instructor and a "large class." The tutor circulates and, almost in a Guided Design[50] approach, facilitates all the groups concurrently. A disadvantage to this approach is that groups inevitably complete tasks at different times. This forces all the groups to follow the same timeframe. This option is not discussed in this paper. Another option is to provide guided questions,[51] which seems to be similar to the method used in Guided Design.

Whether the groups are tutored or tutorless affects three things, a) major student concerns, b) the possibility of including skill development (Schmidt's type II aPBL), and c) the problem format. *Student concerns:* Students in tutored and tutorless groups have different concerns. For the tutorless groups the major concerns relate to reliable student participation (all are not seen as pulling their weight, attendance, lack of trust, lack of cohesive goals, and hesitant to engage in accountability activities).[44] The presence of a tutor, by and large, eliminates this type of concern.[44] For tutorless groups, one approach to address the main concern in tutorless groups, namely, individuals contributing their share, is to use self- and peer assessment.[46,47]

Skill development outcomes: for tutored groups, besides the subject knowledge acquisition (type I aPBL), the program outcomes may include the development of skills specific to the profession (type II aPBL). For engineers, troubleshooting, product or process design, and process improvement might be the skills. For medical professionals, clinical skills would be developed.[6,8] If the aPBL outcomes include skill development, then most institutions use a tutored group. The tutor's role is primarily to facilitate the development of thinking skills and problem-solving/clinical/troubleshooting/ detective skills. Guidance is given by Hmelo-Silver and Barrows.[52] On the other hand, for tutorless groups,

- *the questioning to prompt critical thinking can be handled by a student in the group using questions summarized by Hmelo-Silver and Barrows,[52]*
- *the task and morale aspects of group work are facilitated by the chair,*
- *the development of clinical/troubleshooting/detective skills is probably best developed using separate triad workshops.[53]*

Problem format. For type I aPBL, a single page, single problem is usually used. For type II aPBL developing clinical/troubleshooting/detective skills, the group receives, over the weeks, a sequence of related problem statements representing the stages of the process.

The resources and the university culture often dictate whether to use tutored or tutorless groups. This decision affects the student issues we need to address; whether clinical, troubleshooting, or procedural skills can be included as a target outcome for aPBL and the type of problems created and their sequence.

2. Some of what it takes to implement aPBL

Here are seven issues to consider.

2-1. Prepare the students before aPBL with skill in problem solving, teamwork and self-assessment. Many[20, 30, 33, 54-56] have found it vital to provide workshop-style training or to ensure students have skill in such areas as problem solving, self-assessment, and group skills before they engage in aPBL. For example, at the McMaster University Medical School one of the five criteria for admission is successful performance on problem solving and group work as measured by observers of a group doing a simulated aPBL task.[54, 55] In the McMaster Oncology program, one of the first activities is a workshop on problem solving before aPBL. In the McMaster Chemical Engineering program students have a minimum of 12 hours of workshops on problem solving (4 h), stress management (2h), change management (2h), self-assessment (2h), and group work (2h) before they work in the aPBL format.[20, 57] For each workshop, students submit a self-assessment journal.[20] To facilitate the students teaching each other, it helps if each knows the learning style/preferences of others in their group.[39] Each student receives feedback from the following inventories: Jungian typology (Myers Briggs Type Inventory),[57-59] Kirton Adaptive Innovative,[57, 60] Lancaster Approaches to Studying,[57, 61, 62] and Perry.[57, 63] This information is shared with other group members. Each group invests an hour to decide on the norms for that particular group.[64] In addition, a 6-hour introduction to aPBL is given.[47, 49]

In the Netherlands, students have workshops on group collaboration skills before aPBL.[56] This includes mastering the seven-step standard procedure to translate problems into learning issues for individual study, structuring the group communication process, learning how to chair meetings, and learning how to effectively be the scribe. At Maastricht University there is more structure in the first year to provide extensive training in problem discussion, chairing meetings, and reporting findings.[30]

Mantri et al.,[33] in an electrical engineering program, provided two training sessions for students on teamwork, problem solving, and an introduction to aPBL.

2-2. Scale back to the fundamentals

For well-functioning teams about 30% of the contact time is spent on questioning, checking, task problem solving activities, and morale building.[65] For poorly functioning teams, as much as 70% of the contact time might be spend on the process of making the team work, leaving only the remaining time for the actual teach/learn process.[65] It should come as no surprise, then, to realize that in aPBL the subject knowledge "learned" is about 70 to 80% of what would be "covered" in lectures. Therefore, focus your learning objectives and the problem learning issues on 80% of what you might "cover" in lectures.[14, 66] At McMaster we achieved this by removing duplication among courses, focusing on the fundamentals, and minimizing the instructor's interesting—but not essential—enrichment.

2-3. Create the resources

Study resources for the students and room facilities need to be provided. For the study resources, I have found it helpful to provide the students with the set of visuals/PowerPoints that I used when I lectured and an annotated list of resources they might find useful. Such resources were placed on reserve in the library. For one subject that I thought was challenging for the students to understand I prepared a videotape lecture. With more than 1,000 students going through the program, that videotape was viewed by only one person.

Other resources needed include rooms with flat floors, moveable chairs and tables, and white boards for each group. Throughout the sessions the groups will be brainstorming, raising issues, seeking clarification, and summarizing. Barrows suggests that a white board or summary projection of the ideas be available to help focus and speed the process along.[9]

2-4. Use reflective journals

Many[5, 7, 20, 30, 68, 69] recommend that the students benefit from writing reflective journals. As noted in Section 2-1, students wrote self-assessment journals[20, 48, 57] for each of the process skills workshops.

We continued to have them write self-assessment journals for the chairperson skills and the life-long learning skills being developed through the aPBL activities.

2-5. Anticipate problems

In general, in either tutored or tutorless groups, some stress occurs because of the change in learning environment but more directly because of the change in student expectations of the instructor. Perry's model can be used to guide instructors and students.[5, 24, 63]

Stress, even with tutored groups, can debilitate and frustrate the groups. Solomon and Finch's analysis[70] of tutored groups suggests that the major additional contributors to stress, in addition to the above-mentioned stress related to student expectations of the instructor, include:

1) *uncertainty of the breadth and depth of knowledge required,*
2) *time needed for self-directed study,*
3) *misunderstanding of aPBL and faculty role,*
4) *lack of confidence in one's ability to be successful.*

This theme is stressed in Chapter 1 of the student guidebook.[5] Options are given to help overcome the stress of change.[5]

2-6. Understand the amount and type of work required of the instructor and students. aPBL requires a lot of up-front preparation.[7,48] The teacher prepares the learning objectives, creates a list of resources and additional learning material, and locates a room with flat floors with moveable tables and chairs. The problems are created, tested with sample readers, and revised. Students are assigned to groups, chairperson duties are assigned throughout the semester to give each a chance to chair at least three different meetings, and policy details are published about attendance, failure to hand in reports, and inadequate participation.[48,49,57,71] For the training workshops, described in Section 2-1, teachers learn how to facilitate the workshops[57]; this takes about 3 hours per workshop. Teachers run the workshops and mark the self-assessment journals submitted by each student for each workshop. Marking takes about 30 min/journal. For the inventories (Jungian, KAI, Perry, and LASQ) students can self-score these and explore the implications by viewing the PowerPoint presentation for the MPS Unit 11, the Unique You.[57]

Just before the students start aPBL as groups, the teacher introduces aPBL, as mentioned in Section 2-1, with resources and details of how to do this described elsewhere.[47,49] Part of this 6-hour briefing includes a videotape of students experiencing the three aPBL sessions: the goals meeting, the teach meeting, and the exam/feedback meeting.[72]

The students receive training through the workshops. For each of Goals, Teach, and Feedback aPBL sessions that result from each problem, the designated chair prepares and circulates the agenda. At the Goals meeting, the students identify what they know already and create five to six learning objectives for what they need to know. These are validated by the teacher.[48] Each contracts to teach one of objectives.

Each, armed with the learning preferences of his/her team members, researches, learns, and prepares teach notes to be handed out at the Teach meeting. At the Teach meeting, each receives feedback about the quality of the teach.[48] For the Feedback meeting, each student prepares a good 10-minute "exam" question (and answer) on a topic that he/she didn't teach. At the Feedback meeting, the group selects the best question to pose to another group. Each group writes an answer to the posed question they receive. After 30 minutes, their response to the posed question is marked by a student marker from the other group that posed the question. Each group then debriefs about their performance on the test and their understanding of the new knowledge. The teacher collects and marks all the evidence (the posed question and poser's answer, the other group's written response and the marking of that response). At the end of each cycle of three meetings, the students submit a self-assessment journal.[48,57]

The teacher monitors the Goals and Feedback meetings to ensure that all people are participating. If some are missing, the group is asked if they want the teacher to enforce their guidelines for dealing with delinquent, non-participating members. Usually the result is that the delinquent person is sent "the letter."[71] In our experience, about 10% of the students receive the letter once. They then negotiate to be readmitted to the group. Of the 150 who received the letter (over 25 years of using aPBL) only one decided not to seek readmission and preferred to learn on his own.

2-7. Create problems

From the problem, students will identify learning issues that equal your learning objectives for a lecture course. The general guidelines for creating any problem are:

1. *The learning goals are achievable: allow about 3 to 5 hours of study/prepare teach notes for each individual student. Each problem would have about 5 to 6 learning*

TABLE 1
How the role of the tutor and the desired outcomes affect the form of the problem.

		Outcomes: knowledge plus listening, critical thinking, questioning, assessing validity of information	
		aPBL I, subject knowledge	aPBL II, knowledge plus clinical/trouble shooting/detective skills
tutorless group		**student** given "question checklist" for critical thinking, questioning, assessing validity of information	difficult to do; develop skill after knowledge gained from aPBL via separate triad workshop[53]
tutor	facilitating several groups		**tutor** guides the group through the clinical/troubleshooting/detective process. Challenge, groups progress at different rates and force group to follow template process. Perhaps overcome this via astute problem sequence.
tutor	with each group	**tutor** asks prompting questions for critical thinking, questioning, assessing validity of information	**tutor** guides group through the clinical/trouble-shooting/detective process.
form of problem		short, single scenario problem	series of problems: learn knowledge and tests to perform; test results and subsequent decision about action; action and follow-up.
usual discipline		any	health sciences, engineering, police.

objectives for a group of six students so that each will research/teach a major topic.

2. *The learning outcomes are consistent with the stage of development of students and builds on and activates prior knowledge.*
3. *Goals might integrate knowledge, skills, and attitudes across subjects and disciplines.*
4. *The problem contains "cues" such that the students create learning objectives that are identical or close to those of the faculty.*
5. *The problem is at an appropriate level of complexity.*
6. *The problem statement is not too restrictive. This challenges the student's thinking and expects the student to integrate the new knowledge with the old.*
7. *The problem is motivational and relevant.*
8. *The problem is similar to professional practice.*
9. *The problem promotes student activity.*
10. *The problem includes raw data, like are encountered in practice.*
11. *The problem identifies the context.*

In addition, the ***form*** of the problem you create depends on the expected outcomes in terms of the subject knowledge **and** the skills you want to develop. Table 1 lists the impact of the outcomes for aPBL on the form of the problem.

aPBL Type I, when the outcomes are subject knowledge plus critical thinking. For these outcomes my experience is that you can work with tutorless groups, and the problem is usually a single problem statement. A student can handle the role of the missing tutor (to ask questions and check understanding and link to past knowledge) via a checklist of "facilitator question prompts." The skill in problem-solving is developed through workshops ahead of time or applicants are not admitted into the program unless they have demonstrated skill in problem solving. An example of aPBL I problem in Chemical Engineering is given below.

Example problem for aPBL I: Process safety

Context: Chemical process analysis. For the past three weeks we have been analyzing the process to make maleic anhydride from butane. The students have the detailed Process & Information Flow Diagram.

Target learning objectives:

Given the name of a chemical, you will be able to identify whether the chemical is on the EPA Hazardous Organic NESHAP (HON) list, the HON Section F list.

Given various sources and data for the hazardous nature of chemicals, you will be able to define the terms and interpret the degree of hazard and the implications.

Given a process, you will be able to use HAZOP (or equivalent procedures) to identify the conditions for unsafe operation and recommend corrective actions.

Ideal but not critical learning objectives:

You will be able to describe the Natural Step approach and apply it to this process.

Problem statement:

Upcoming visit from Occupational Health & Safety

> You are the process engineer for the maleic anhydride process. Recently, a process in the United States, similar to ours, exploded. Fortunately no one was injured but the ensuing fire caused 1/2 million dollars U.S. damage. Furthermore, new environmental legislation is being proposed that really clamps down on emissions and water discharge. We also are having a visit, in four months, from the occupational health and safety branch of the government. Your supervisor requests that you systematically look over your process.

Comment: This problem description seems to satisfy the criteria of 2) builds on previous knowledge, 3) multidisciplinary, 6) not restrictive, 7) motivational, 8) authentic professional practice, and 10) only raw data are given that are typical of professional practice. Therefore this case satisfies most of the criteria. Trials with students, however, showed that the students failed to generate all the target learning objectives. Insufficient cues had been given. The case was rewritten to include cues such as chemical process, exploded, emissions, water discharge, environmental legislation, government, health and safety, HON, systematically identify potential hazards for a process, HAZOP, and sustainability.

New Problem Statement: ***Upcoming visit from Occupational Health & Safety***

> You are the process engineer for the maleic anhydride process in a Canadian company. Recently, a process in the United States, similar to ours, exploded. Fortunately no one was injured but the ensuing fire caused 1/2 million dollars U.S. damage. Furthermore, new environment legislation is being proposed that really clamps down on emissions and water discharge. We also are having a visit, in four months, from the occupational health and safety branch of the government. Your supervisor requests that you systematically look over your process.
>
> As you are thinking about this assignment, Kim walks by and suggests that the HON list would be helpful; Kim suggests that the HAZOP approach is a good systematic way to solve the problem.
>
> "Is sustainability something I should also consider?" Kim thought for a moment and then suggested that this was not a direct concern for this problem, but the visitors would be impressed if we had at least thought about sustainability.

Checklists, suggestions, and examples of creating problems are available from Barrows and Wee.[3]

aPBL Type II. When the outcomes are subject knowledge, critical thinking and skill in clinical practice or troubleshooting. Usually this option requires a tutor to be present in the group. The key feature is that clinical or troubleshooting skill is also an expected outcome. The problem is posed as a series of scenarios and the students work sequentially through the cases over a several-week period. Examples are available in the medical and nursing disciplines.[48] In chemical engineering transport courses, fundamentals can be learned through troubleshooting problems. For example, the initial problem could be a faulty pump that requires students to learn the Bernoulli equation, system analysis, and pump characteristics. After the students have learned those fundamentals, the second problem would provide answers to questions that might be asked to try to locate the fault. Such questions might be "When was maintenance done?" or "Look at the flare, to see if there are upsets on site." Once the students have seen the benefits of asking this type of question and have further enriched their knowledge of pumps and systems, the third problem would list tests and the results of tests. These might include a comparison of the pressure when the outlet is shut with the head from the pump curve at zero flow or the results of the ampere measurement to estimate the power drawn by the drive motor. So the problems continue until the fault is detected and corrected, the students reflect on the troubleshooting process used and on the knowledge gained. I am unaware, however, of any problems in chemical engineering that have been prepared in this way for aPBL Type II.

SUMMARY

In this paper the focus is on what Barrows called authentic or original PBL where no lectures are given, students learn new knowledge, and all students in the group must learn the new knowledge.

Institutions using this form of aPBL have found that, compared to traditional lectures, marks in subject knowledge are the same; clinical or troubleshooting skills are better; deep learning is promoted instead of surface learning; surveys of graduates and alumni are positive; student motivation is higher; student retention of the knowledge is higher, graduates have improved skill in gathering data, and there is improved efficiency in the graduation rates with fewer dropouts. In addition, the following career skills are developed: problem solving, teamwork, confidence, life-long learning, information gathering, interpersonal relations, and communication.

To implement an aPBL learning environment, we need to decide whether tutored or tutorless groups will be used. For tutored groups, one tutor is needed for each group of five to eight students. For tutorless groups, the students have to be trained with the skills needed to function effectively without a tutor. Seven concerns include preparing students for aPBL, scaling back to the fundamentals, providing the literature and room facilities needed, using reflective journals, anticipating problems, investing the up-front work to set up aPBL, and creating the problems that will drive the learning.

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