MULTIPLE PERSPECTIVES ON MEETING THE CHALLENGES
OF PBL IN THE SCIENTIFIC DISCIPLINES

S. V. Springham, T. F. Chia, S. S-L. Lim, G. H. L. Cheang & A. Y. Chen
Nanyang Technological University, Singapore

Abstract: There are several definitions of Problem Based Learning (PBL). For example, those of the Basudur Simplex Model, Kaufman and Swartz. The common features are: 1) Find and define the problem; 2) Examine facts and possibilities; 3) Consider alternative solutions; 4) Implement the best solution and 5) Problems should be related to the “real world”. However, in the natural sciences and mathematics, one often proceeds from “real world” problems to the conceptualisation of the abstract. Conceptualisation of the abstract is one of the tenets of the natural sciences and mathematics. Perhaps it is required less in the biological sciences, but it is increasingly required in physics and almost entirely in mathematics. The usual definitions of PBL have to be adapted to take into account the fact that conceptualisation of the abstract, rather than solving “real world” problems, is the end-product of many problems in the scientific disciplines. We give examples and counter-examples of the applicability of PBL integrated with information technology in our disciplines.

The Development of Problem Based Learning

The pioneers of problem based learning (PBL) were the medical schools of Case Western Reserve University (USA) in the 1950’s and McMaster University (Canada) in the 1960’s. Barrows and Tamblyn (1980) in their groundbreaking book, set out the rationale for PBL and a structure for applying PBL in medical courses. The main features of the McMaster model of PBL are given be Barrows (1986) as:

• Learning is student centred
• Learning occurs in small groups
• Teachers are facilitators or guides
• Problems form the organising focus and stimulus for learning
• Problems are a vehicle for the development of clinical problem solving skills
• New information is acquired through self-directed learning.

Since its introduction, PBL has become increasingly widely used in other medical schools. Moreover its use has spread to other tertiary education environments in a number of vocational professional programmes, including architecture; dentistry; nursing; social work; and construction management (Toottell and McGeorge (1998)).

Many of its proponents have hailed PBL effusively as a major development in education. For example Boud & Feletti (1997) said of PBL that it is “the most significant innovation in education for the professions for many years.” Some of the often-quoted advantages of PBL by comparison with more traditional teaching methods are:

• acquisition, retention and application of knowledge are enhanced
• enhances students’ problem solving skills
• promotes creative and critical thinking
is multidisciplinary and integrative/holistic in nature
• increased student interest and motivation
• learning is self-directed
• promotes collaborative learning
• enhances students’ social and communication skills
• enhances student-faculty contact.

As numerous practitioners have emphasised the selection and construction of the problem is critical to the success of PBL. Firstly, the problem must involve the concepts and principles relevant to the content domain and the learning objectives of the module. Secondly, a suitable PBL problem should be authentic and ill-structured. An example of an authentic/real-life problem would be the case-notes for a patient arriving at a hospital emergency room displaying a collection of symptoms. The students, working in small groups, would be asked to make a diagnosis and prescribe treatment. The incompleteness of the information given is part of the ill-structured nature of the problem, and the students would have to propose what further medical investigations and test should be conducted. The teacher, as facilitator, would provide the results of these hypothetical tests, and some guidance when deemed necessary. The problem then becomes the vehicle for the development of the students’ problem solving skills, and the stimulus for their self-directed learning of the required theoretical knowledge.

The rapid growth of PBL is convincing evidence that it has been a largely successful development in the teaching of professional programmes. However, a number of difficulties and pit-falls have been noted. These include:

• assessment and evaluation issues
• less coverage of syllabus
• students’ feelings of being overwhelmed
• students spending excessive time on extraneous aspects of the problem
• increased staff workload in building problem repertoire.

It interesting to note that the use of PBL has expanded rapidly in professional and vocational programmes, but it seems to have spread hardly at all to some traditional university subjects such as the natural sciences, mathematics, literature, etc. For the case of the natural sciences, it is likely that part of the reason for this lack of use, lies in the increased difficulty of finding real-life/authentic scenarios for subjects which are predominantly theoretical in nature and do not have a tight vocational focus. Moreover for subjects so concerned with rigour and exactness as mathematics and physics, the notion of dealing with ill-structured problems is from a traditional point of view, almost antithetical.

In considering how we can employ PBL effectively in our respective scientific disciplines, we have tried to focus on the definition of PBL given by Barrows and Tamblyn (1980):

“...the learning which results from the process of working towards the understanding of, or resolution of, a problem.”

This emphasis on process and the development of problem solving skills is of course central to the scientific disciplines. Indeed, such a problem solving process is at the heart of all scientific research, which is in a sense the ultimate form of PBL. Research has traditionally always been part of the undergraduate curriculum in the form honours or final year research projects. However, the
substantial content knowledge required for such research work has restricted its use in the earlier years of undergraduate science degrees. In recent years a number of initiatives have been launched, in Singapore and abroad, to involve a wider group of undergraduates in the research work of university lecturers. This exposure to scientific research has certainly been beneficial in enhancing students’ awareness of research as a career option, and in giving them a clearer understanding of the what and why of scientific research. However it is often the case that, except for students of exceptional ability, their limited background knowledge and understanding of relevant concepts prohibits a deeper engagement in the research work, i.e. the students are forced to rely too heavily on supervisors, mentors and research students.

Hence the authenticity we should seek to create for our students, is not that of forefront scientific research, but rather that they should be engaged in higher order creative and critical thinking, scientific discourse, and the type of problem solving skills that will be required in their future lives. In other words we want our students to learn how to learn. As expressed by Honebein (1993) “an authentic learning environment is one in which the cognitive demands, i.e., the thinking required, are consistent with the cognitive demands in the environment for which we are preparing the learner.”

Although at present, the use of PBL is predominantly to be found in vocational professional degrees, a number of interesting initiatives aimed at implementing modified forms of PBL have begun in science programmes over the past few years. In our view, the following projects are of particular significance:

- Problem-based learning for all basic science classes at the University of Delaware [1]
- Illinois Mathematics and Science Academy’s Centre for Problem-based Learning [2]
- Rensselaer Polytechnic Institute’s development of the studio-format for introductory science courses [3]

**PBL in Biology (by T. F. Chia and S. S-L. Lim)**

Student success and learning in biology is mediated by the interaction of characteristics of the student and the classroom environment inclusive of the teaching methodology. In the teaching of many biological subjects, Project Work (PW) ranks importantly in the teaching course. PW is especially helpful in exposing the students to real-life happenings in Biology, which is essentially the scientific discipline involving the study of life. From the description and analyses of the characteristics of PBL elaborated earlier, it can be seen that the steps involved in hypothesis formulation, design of project, and testing of the hypothesis, involve and capitalise on the strength of both PBL and PW. A well thought out PBL exercise, implemented into a good PW environment, will lead to a unique circumstance which will expedite the deep learning, skilful decision making and multiple tasking of the students. In this respect, we will now discuss and draw upon two cases: the teaching of statistical ecology and molecular engineering of organisms.

In the teaching of statistical ecology of marine life in an inter-tidal setting, many components are involved and biological interactions of the organisms can be rather complex. Physical measurement and analysis of each component in relation to the ecological environment is a rather perplexing topic to teach in a classroom setting. Students will inadvertently miss the dynamics of species interaction and survival. What we have done in class is to lay down the basics of statistical ecological principles and formulate certain hypotheses based on this framework and let the students structure them accordingly. The most important process is to let the students test and gather data in
a real-life setting when they carry out field work at the beach. Students have found that even with the most meticulous preparation in class, they will always be confounded with unforeseen problems in the field. It is particularly this contrasting situation of both classroom and real-life ecological problems that students are exposed to the rigours of the subject, and develop the experience and passion for biology which makes the teaching and learning fun for both students and teachers.

Similarly in the teaching of molecular engineering of organisms, learning through theories and examples from abroad, is insufficient for students. We discovered that real-life situations have to be created for the students, so that they can have first hand experience. With the current controversy over genetically modified organism, active involvement of the students in genetic PW will help them grasp the overall picture. Therefore an exploratory PW with in-built PBL was designed with the objective of helping the students to improve their performance and better judge their own understandings of the subject matter. Students were assigned projects that involved the genetic modification of local plants and animals, using different transformation techniques as well as different genes. A typical ill-structured molecular-genetic problem commonly found in PBL was designed as a molecular biology project to foster identity with the subject. The scientific rigour will provide the discipline, and the carefully crafted “modular” project is to provide stage by stage confidence building through its novelty of approach.

In this exercise, we concentrated on building the confidence, decision making and learning process of students taking the subject, by involving them in the PW. This should help to instil a disciplined approach and an enhanced interest in studying the subject. This PW provided the students with further opportunities to actively participate in scientific practices. The beginning was slow and sloppy, mainly because the students have never been exposed to such a perplexing situation with an entirely open environment, yet bounded by the rigour and regimentation of scientific principles. However, after a period of adjustment and error making, with constant guidance and encouragement from the mentor, the students undertook the project with much zest and creativity. The project experiment was well conducted by the student and the first goal of the project was quickly achieved. By the end of the sixth month, it was evident that this participation had increased the students’ competence in designing experiments for class activities. The interest in the subject during lectures improved markedly and students showed openness, interest and confidence. On the whole, the students’ involvement with the subject and the level of student-teacher interaction increased very significantly.

PBL in Mathematics (by G.H.L. Cheang)

Bloom’s (1964) taxonomy of learning suggests that in any discipline, one must first acquire the basic knowledge of the field, followed by a deeper comprehension. This is followed by the application of the knowledge to analyse problems, to synthesise new theories and to evaluate the effectiveness of the new theories/products. The problem based learning paradigm is also loosely based upon Bloom’s taxonomy of learning. In depth learning is said to take place when the student is able to apply his knowledge of the subject to solve real world problems; and to synthesise new products as in the case of certain disciplines. When loosely structured real world problems are solved and new products are discovered, critical thinking is employed. However, in the mathematical sciences, the conceptualisation of the abstract is a basic tenet of the discipline (see Courant and Robbins (1947), Hardy (1940)). Mathematicians often start from observations regarding real world problems, and then generalise the concepts involved in very abstract terms. Thus the basic tenet of mathematics, the conceptualisation of the abstract, appears to diametrically contradict what is espoused in the problem based learning paradigm. However, when viewed in terms of providing students with cognitive demands which are consonant with learning objectives
and the culture of mathematics, I believe there is considerable scope for the effective use of a modified PBL approach in mathematics.

An example of a modified small group PBL approach I have employed, is the honours level probability module. The most recent class comprised four students majoring in mathematics, who have all taken one prior module on probability. The module covers standard mathematical tools in probabilistic modelling such as characteristic functions, distribution theory and convolution. Using these standard tools, students study Poisson processes, renewal processes and discrete time Markov chains in detail.

The group based Socratic method (Brown and Atkins (1988), Broudy (1963)) is employed primarily in teaching these students. Although the students have a main reference textbook (Ross (1992)) to refer to, this is mainly used to compare and contrast theoretical results obtained in the class. The teaching approach is deliberately informal. At the start of each new topic, students are given vague outlines of what the topic is about. The students are encouraged to come up, as a group, with their own definitions of the terminology required to describe the process. Questions are raised to guide them along and to help them focus on the objectives of the stochastic model they are supposed to formulate at the end of the session. The students also have to prove whether their own formulation of the process is equivalent to the standard formulation found in the text. In this way, the students get a chance to discover the mathematics for themselves. They question each other and brainstorm in order to formulate other models by adding or relaxing the assumptions on existing theorems. Since this is a small group, a lot of collaborative learning among the students also takes place.

In this context, the “problem” is the abstract formulation of the stochastic process. Phenomena such as irregular arrivals of telephone calls and buses are used to motivate the abstract formulation of certain renewal processes. The students are not given the mathematics and asked to model “real world” phenomena. Instead, “real world” phenomena are used as a pointer towards a finer abstraction of the mathematical concepts. The Socrates method of teaching satisfies some of the features of problem based learning. However, the end-product of the discipline is not the usual end-product of the problem based learning paradigm. In the mathematical sciences, striving for the abstract is a basic tenet of the discipline. Thus, any problem based learning paradigm for mathematics should also cater to this tenet.

PBL in Physics (by S.V. Springham)

Two areas in which a modified PBL approach can be used effectively in physics are firstly, in re-engineering the first and second year teaching laboratories as micro-research projects, and secondly, by the use of Case Studies in Science following the model of the State University of New York at Buffalo.

A recognised problem with undergraduate physics laboratory experiments is that they are commonly conducted in a ‘cookbook’ fashion, with the students simply performing the steps as prescribed in the experimental manual or as shown to them by the demonstrator. Such an approach places the emphasis on the product of the experiment (e.g. the measured value of a physical quantity) and not on the process of solving a problem. As expressed by French (1978), “…it is in this area (of laboratory work) that we tend to feel most strongly, and most often, that our students are having an educational experience falling far short of what we would wish them to have.”

Consequently, I have sought to employ PBL as a means of turning these previously rather routine experiments into a series of micro-research projects. The intention being to eliminate the cookbook routine, and promote a deeper investigative/problem-solving approach. For example, the laboratory
experiments undertaken by the first year thermal physics class are not now conducted in a laboratory session separate from lectures and tutorials as in previous years, but rather these elements are treated as an integrated whole. The two experiments conducted in this module are (i) measuring the thermal expansion coefficient of different metals, and (ii) investigation of the Stefan-Boltzmann radiation law. These experiments are performed with groups of three to four students, and each experiment lasts two hours: one hour from each of two consecutive weekly sessions. In the usual cookbook approach one experiment would be conducted in a single two-hour session and the report submitted the following week. By spreading each experiment over two sessions (although keeping total duration the same) students are given time to reflect on the concepts and problems associated with the experiment, and engage in group discussion and self-directed learning related to these problems.

In the preparation of experimental guidelines and instructions to the students, care was taken to ensure that the experiments were not too 'tidy'. But rather that there were a number of loose ends, open ended questions, and pointers to possible extraneous factors and sources of error affecting the results of the experiments. The arrangement of the experiment was such that most of these loose-ends would be encountered in the first session, so that students would have the intervening week to consider these points individually and in groups. To further stimulate this process, the first week’s session was rounded off with a question and answer session in which they could quiz me on these points. I emphasised that by the following week’s session they should, as a group, have reached some (perhaps tentative) conclusions regarding these points. Such conclusions would include which sources of error were negligibly small and could be safely ignored, and which others needed more careful treatment – perhaps resulting in modifications to the experimental procedure or apparatus.

With regard to the use of real world case studies for teaching physics, an example of the kind of study which I believe is valuable, arises form a frequently used tutorial question on thermal expansion: calculating the gap between rails laid end to end on a railway line. In its typical form the question states the length, thermal expansion coefficient and temperatures range – the calculation is straightforward and by no means exciting. How much more interesting it would be to contact Singapore MRT and really find out what gap they used, and why? On what historical weather data do they base their prediction the highest possible temperature? What type of steel is used for the rails, and why? What is the tolerance on the gap measurement and what extra allowance is made for this uncertainty? What other questions do the students think are important? Such a case-study approach will certainly be far more engaging and promote significantly deeper learning than the mundane tutorial question from which it stems.

Lastly, in my view the State University of New York at Buffalo’s web site [4] is one of the most valuable resources for science lecturers interested in exploring the use of PBL. It contains a sizeable collection of case studies with teaching notes, useful pointers for developing case studies of ones own, and a number of enlightening on-line articles concerning teaching with case studies and PBL.

Conclusions

In this paper we have considered both the potential advantages and problems associated with inclusion of PBL in the teaching of our respective scientific subjects (biology, mathematics and physics). In particular we have sought to examine how PBL can be employed most effectively to achieve deeper, more meaningful learning and enhance students’ creative and critical thinking skills, and make them more adept at the kind of problem solving process which is at the heart of scientific research. We also described the initial steps we have taken to introduce elements of PBL into our own teaching and the outcome of these initiatives. One of our principal conclusions is that a “pure” PBL approach, such as the McMaster model, is not the most appropriate for the teaching
of the scientific disciplines. The reasons for this lie mainly in the fundamentally theoretical nature of science, the necessity of abstraction, and the lack of a tight vocational focus. However we have found that modified forms of PBL employing scientific case studies, project work, field work, group-based Socratic method, and micro-research projects, have a great deal to offer in terms of promoting higher order thinking and problem solving skills in our students. These conclusions are summarised in Table 1.

Table 1

| Scientific research is the ultimate form of PBL. | Students are ill-prepared for research in early years of undergraduate programme. |
| Authenticity should lie in “consistent cognitive demands”. | “Real-world” authenticity is problematic. |
| Traditional tutorial questions presenting all and only necessary information do not promote higher order thinking skills. | Posing problems which are ill-structured in nature, should not be done at the expense of rigour and exactness. |
| Scientific case studies, project work, field work, and group-based Socratic method (i.e. modified-PBL approaches) are a good means of engaging student interest and encouraging higher order thinking skills. | Scientific subjects do not have a tight vocational focus. |
| Present-day and historical scientific controversies, the history of science, inventions and patents are a good source of case-studies/problems | Conceptualisation of the abstract is central to science, and even more so to mathematics. |

References


**Referenced Web Sites**

[1] [http://www.udel.edu/pbl/](http://www.udel.edu/pbl/)

[2] [http://www.imsa.edu/team/cpbl/cpbl.html](http://www.imsa.edu/team/cpbl/cpbl.html)

[3] [http://www.ciue.rpi.edu/studioteaching.html](http://www.ciue.rpi.edu/studioteaching.html)

[4] [http://ublib.buffalo.edu/libraries/projects/cases/case.html](http://ublib.buffalo.edu/libraries/projects/cases/case.html)