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A problem based learning (PBL) application for the teaching of Mathematics and Chemistry in higher schools and tertiary education: An integrative approach

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In this paper, we present the concept of problem-based learning as a tool for learning Mathematics and Chemistry, and in fact, all sciences, using life situations or simulated scenario. The methodology involves some level of brain storming. Here, active learning takes place and knowledge gained by students either way through a collaborative learning situation becomes personalized within the group. This underscores the need for the integration of the curricular of some basic concepts in Mathematics and the sciences in general from the school level; thus it makes it easier for students in the tertiary educational level to learn higher and applicable concepts. Three cases were discussed involving PBL namely: Graphical interpretation of experimental readings in a Chemistry/science laboratory as it enhances or makes use of basic mathematical knowledge, calculus in Chemistry and lastly, the integration of curricular for Mathematics and the basic sciences at higher secondary and lower university levels. Problem-based learning method then becomes an enviable tool which can be used in teaching both Mathematics and Chemistry at the secondary and tertiary levels.

Key words: Problem-based learning, active-learning, personalized knowledge, collaborative learning, calculus, integration of curricular.

INTRODUCTION

Problem-based learning (PBL) has been applied for over twenty years in different fields of education in many countries. The first and best-known applications of PBL are in the study of medicine during the 1960s (Barrows, 1985, 1996). Since then, PBL has spread worldwide to other disciplines in higher education such as architecture, economics, engineering, mathematics and law. Problem-based learning has often been understood only as a method of learning. What distinguishes PBL as a teaching technique, an educational strategy, or even as a philosophy is the changes in the whole learning environment that the approach requires. Defining PBL as an educational philosophy means holistically considering a number of elements: the organizational context; curriculum content and design; and the teaching and learning approach, including the method of assessment and evaluation.

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Although problem-based learning has been investigated in the context of education, the theoretical basis of PBL is closely connected to learning in the work place. PBL runs the same risks as any other progressive pedagogical idea: the baby might be thrown out with the bath water. PBL can fail, for instance, because of mechanical application, or because no changes have been made on the curriculum level or because the assessment and evaluation system has not been developed in response to the new ideas about learning. In this article we examine the basis of PBL knowledge and the prerequisites for the development of curricula and for the assessment of problem-based learning.

The basic premise of problem-based learning (PBL) is that learning starts from dealing with problems that arise from professional practice. Traditionally, education has been organized according to the logic of separate disciplines and subjects. However, because professional practice and individual learning processes do not follow such divisions, this has led to a widening gap between education and professional practice in the work place (Boud, 1985; Boud and Feletti 1991; Poikela and Poikela, 1997; Poikela, 2003). PBL gathers and integrates many elements regarded as essential in effective, high quality learning, such as self-directed or autonomous learning, critical and reflective thinking skills and the integration of disciplines.

In epistemological discussion, knowledge is usually divided into theory and practice. Theory is understood as propositional knowledge (knowing-what), and practice as procedural understanding (knowing-how). In a broader sense, the relationship between knowledge (what) and knowing (how) can be understood as a debate between Cartesian finite and Heideggerian changing knowledge. The former represents the modern idea of permanent knowledge and the latter, the post-modern way of apprehending knowledge as changing and dependent on the context of the activity rather than on facts or truth. In PBL, knowledge is seen as being more closely aligned to the post-modern than the modern view of epistemology (Cowdroy, 1994).

Skill in metacognition is also essential for successful learning in PBL environments. However, this skill may not be enough in engineering due to the nature of the knowledge domain. In PBL, the order in which topics are learned is partly defined by the students themselves and hence some topics may be overlooked. Perrenet et al. (2000) describe the medical knowledge domain as having a “rather encyclopaedic structure, so the order in which various concepts are encountered is not prescribed and further learning will hardly be affected by missing a topic”. In other words, if a topic is missed now, it can be filled in later. By contrast, Mathematics, Physics, Chemistry and much of Engineering have a hierarchical knowledge structure. Many topics must be learned in a certain order, because missing essential parts will result in failure to learn later concepts. This problem will be hard for a student to correct, no matter how good their meta-cognitive skills, because they probably cannot fully compensate for missed topics as a result of using a PBL method. The issue of the particular hierarchical knowledge structure of much of Engineering is possibly the most fundamental obstacle for implementation of problem-based engineering through an entire engineering program, as opposed to within individual courses in the program.

The problem-based curriculum should be organized as a student-centered learning environment. In concrete terms, this means knowledge acquisition from books in the library and information seeking from the internet, the media and from professional experts in working life. It means that lessons and exercises in school are no longer causes of learning, but resources for learning.

Traditional curricula are taught and therefore also learnt, in a fragmented nature (Bialek and Botstein, 2004). Research shows that learners and students view Mathematics and science as completely separate entities without realizing the links that exist between the curricula. This phenomenon has implications for teaching and learning in higher education as well as in schools (Hannan, 2000). Experience in teaching Mathematics in the university also shows that a highly skewed percentage failure rate in Elementary Mathematics of fresh men in the universities tends towards students who major in other sciences. Traditional curricula are facing pressure to become more integrated and interrelate since a blend of knowledge is required for lifelong and meaningful learning (Finucane et al., 1998). Lifelong learning in general and demand for continuous development of skills, knowledge and attitudes needed in working life; in particular, has resulted in a call for new ways to organize learning. The knowledge gained in education becomes quickly outdated and loses its value for working life. Working life requires new kinds of competencies including independent knowledge acquisition and application, problem solving, co-operative and multi-dimensional professional skills and abilities for continuing learning. Problem-based learning has been one of the approaches to bridge the gap between work and education. PBL is an educational approach that has been adopted in various educational institutions around the world. However, some people consider that PBL is not adequate for Mathematics, and other abstract sciences, since it does not guarantee absolute accuracy and promotes know-how more than what-and-why knowledge for abstract notions.

CHARACTERISTICS OF MATHEMATICS AND CHEMISTRY PROBLEMS

We must be sure of the type of applications to use for deriving a problem in Mathematics and Chemistry. This calls for the nature and characteristics of Mathematics and Chemistry in interacting applications. Of course there are specific characteristics of active learning in Mathematics, and we must be aware of them when building a problem in Mathematics; but clearly Mathematics can be learned by using PBL. Here, we discuss the possible important objection against Maths PBL: usually, in a PBL setting, one gives the students a real ¬life problem and students, in order to solve the problem, must find and study the notions required for solving the problem. How can we find a real ¬life problem in Maths? How can such a problem force students to study the notions (“what and why”) and not only the consequences of the notions (“how to do”)? Actually, the answer is not so complicated. Two types of “applications” can be used. First a “concrete application” in this case it must be clear that the application is only a pretext to study Math, and that main developments must be mathematical ones. This has the obvious consequence that a complete development must not be required in the application domain; on the opposite of course a complete development must be required in the math domain. In other words, professors as students must not forget that the main aim of the study is a mathematical one (Naoum et al., 2008).

In this paper, we shall consider an application which is easily understandable and which allows the integration of both Mathematics and Chemistry. Such applications only use the desired mathematics notions, and possibly not to require students to solve the real ¬life problem itself, and not to go beyond the numerical results (no “concrete production”, in the application domain, is required). Quite often, physical notions are studied with a small number of variables (two or three for example, for computations to be done by hand). As an example, we can re-¬use a problem already used by physicists needing to solve an order two or an order three linear system, transforming it to solve an order n linear system, and so needing to study some parts of linear algebra. The heat equation is often used in only one space variable in thermal lessons, and can be used in two space dimensions for a problem in a Partial Differential Equations PBL setting. No need in this case to build a robot or a rocket or any kind of “concrete” realization, but just to give the numerical results. The same applies to Chemistry concepts and the illustrative examples (PBL problems) in this paper reflect such cases.

The characteristics of a well defined problem in Mathematics and the sciences include the following:

1. A complex task to accomplish by brainstorming
2. A need for several competencies that will integrate knowledge from Mathematics and Chemistry.
3. The presentation shows no direct solution; otherwise it would just be a normal regular assignment.
4. Requires students’ involvement, initiative and team working.
5. At least one learning obstacles should be presented.

REQUIREMENTS FOR CONSTRUCTING A PBL IN MATHEMATICS AND CHEMISTRY TEACHING

In order to build a PBL, we must first define precisely what are the main aims of the course. Here, we concentrate our efforts not in terms of contents, but in terms of competencies, and how the quest for personal knowledge in Mathematics affects/ interrelates with the quest for knowledge in Chemistry. So what are the abilities (the qualities) we want our students to develop? Below is a list which is not extensive, but is required for Mathematics, Chemistry and in fact most scientific subjects.

1. Identifying some specific application areas for basic concepts.
2. Personalising knowledge.
3. Capturing the sense and need for rigor, in both written and oral expression
4. Grasping the need for abstraction and using it appropriately
5. Proving, generalizing and criticizing results
6. Modeling different situations by using the appropriate mathematical tools
7. Interpreting and assessing results.

Of course we also need to develop some specific contents (such as the notions of derivative, of linear mapping, matrix, matrix computation in Mathematics and Chemical equations, graph plotting in simple chemistry experiments, and description of relationship between pressure, temperature and volume as in Boyles law.…).

To implement PBL in Mathematics and sciences, we really want the students to acquire a new notion and not to limit their work to the “how to use it”, which is the quite natural trend of most students. Most students are interested in corner-cutting and escaping with high scores in classroom assessment. This necessitates the need to be more directive for Maths problems than for PBL in other subjects. Thus, it is discovered that giving the students a key-word to properly study and understand may be a good way to guide them without cutting initiatives.

We claim that most of what is known for building a PBL in applied subjects is valid for abstract ones (and particularly in Mathematics and Chemistry). However, we must be more cautious so that the time spent by the student is essentially spent in Mathematics (including oral and written expression), not in the applied domain (such as the production of an object). Quite often, the corresponding work of the concrete object is, for math problems, computer results and for Chemistry some empirical lab readings.

METHODOLOGY

Case one

For graphical interpretation of data students were given short PBL problems in the Mathematics class that integrated functions and graphs that were to be dealt with later in the science class. These problems required students to draw graphs from data obtained from simplistic Chemistry laboratory experiments. The knowledge that was acquired from these problems was then linked to the specific curriculum content addressed in the science curriculum such as, graphs in gas behaviour that describes the relationship between pressure, temperature and volume (Boyles law). This approach was an attempt to assist learners with linking graphs in the Mathematics class to graphs in the science class. This was an attempt to discourage learners from rote learning graphs in science such as the graph of pressure versus temperature ($p = kT$) when it represents the mathematical form of a straight line ($y = mx+c$, where $c = 0$). Thus, all the properties of a straight line (example, gradient, intercepts, directly or indirectly proportional) can be applied to this specific function. A similar example is the graph of pressure versus volume ($p = k/V$), which is the mathematical form of a hyperbola ($y = k/x$).

Case two

Calculus in science

A PBL problem that was initiated in the science class on the topic of electricity (crossed circuits) led to discussions on the definitions of energy, power and work units of power. This discussion was continued in the Mathematics class with the introduction of calculus through the use of rate of change of electrical energy in a household, rather than using the traditional method of using rate of change of displacement (speed) when introducing calculus. The topic was further explored when learners had to plot a graph of electricity usage versus time, as well as interpret the graphical representation.

Case three: On the integration of curricular

We consider here two examples to illustrate the need for integration of curricular for both math and chemistry. The first is applicable at the School curricula while the second addresses the university curricula.

Example One: calculus in Chemistry

A PBL problem that was initiated in the Chemistry class on the topic of electricity (crossed circuits) would generally lead to various discussions on:

1. the definitions of energy,
2. power and work
3. and units of power.

This discussion can then continue in the Mathematics class with the introduction of calculus through

1. the use of rate of change of electrical energy in a household, rather than using the traditional method of using rate of change of displacement(speed) when introducing calculus.
2. The topic was further explored when learners had to plot a graph of electricity usage versus time, as well as interpret the graphical representation.

The outcome of this exercise is that the students would appreciate this integration of knowledge gained by themselves during the PBL tutorial sessions.

SELECTED STUDENTS' VIEW OF PBL IN MATHEMATICS AND SCIENCES

Most research on the influence of PBL on Mathematics and science students has been qualitative. In this write up, reactions collected show that students quickly identify the skills and personal development benefits of PBL and its ability to model a real working environment:

> 'it's better in a group…with everyone's input…you can bounce ideas off each other…and others' ideas might be better. In industry you work in teams' 'better equipped for the future. In the future we'll know (when confronted with real problems) we've done something similar. It gives us group working skills'.

Some appreciation of the differences in approaches to learning between lectures and PBL was also immediately obvious to the students:

> '[With PBL] there's a lot more discussion on what's happening'.
> 'To learn the computational method at the same time as the problem is helpful.'
> 'it helped us to realize – we can do it'.
> 'practical learning… it really helped me to understand and apply the theory…I understand a lot more'

Other benefits were only realized by students in hindsight. These quotes are simulated from students who had participated in four two-week PBL problems during their first and second years but who were interviewed during their third year project;

> 'we felt we needed preparation for PBL but, actually, PBL was a preparation for now'
> 'you have to learn it for yourself, not by preaching…you have to have the experience before you can see how good it is'
> '[it was] excellent learning in a different style'

DISCUSSION

We present here the study to show that PBL in Mathematics and Chemistry is a means of integrating basic knowledge acquired from both subjects in order to proffer solutions to a well posed problem. The traditional way of formulating curriculum in an isolated manner can then be replaced with an integrated approach as seen in this work.

We want to emphasize here that there is no single model for a good problem, and various approaches are possible for deriving a Mathematics or Chemistry problem suitable for a PBL setting. It is, however, necessary to complement PBL work by other ways to do Mathematics, such as usual exercises, numerical experimentation (also possible, of course, within PBL), and to check that students do not share the work, especially that they grasp the generality of the studied abstract notions (but actually we can say that this last point is also true for traditional teaching).

We also want to emphasize the importance of analysing a problem from different angles (context, information given, task, obstacle…).

In order to keep a high students' involvement and motivation, we have to make sure that the sequence of problems allows for varied situations, and so encourages discussions between the students. Of course, an a posteriori analysis of the sequence of problems is necessary to check that all objectives of the course (in terms of student competencies) are adequately covered.

More important than learning science and Mathematics, students need to learn to work in a community, thereby taking on social responsibilities. The most significant contributions of PBL have been in schools languishing in poverty stricken areas; when students take responsibility, or ownership, for their learning, their self-esteem soars. It also helps to create better work habits and attitudes toward learning. In standardized tests, languishing schools have been able to raise their testing grades a full level by implementing PBL. Although students do work in groups, they also become more independent because they are receiving little instruction from the teacher. With Project-Based Learning students also learn skills that are essential in higher education. The students learn more than just finding answers, PBL allows them to expand their minds and think beyond what they normally would. Students have to find answers to questions and combine them using critically thinking skills to come up with answers.

Finally we claim that it is completely possible to construct problems in Mathematics and to relate such to knowledge gained in Chemistry and vice-versa.

REFERENCES

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

Barrows H (1996). Problem ¬based learning in medicine and beyond: A brief overview. In L. Wilkerson & W. Gijselaers (Eds.). Bringing problem ¬based learning to higher education: Theory and practice. San Francisco: Jossey ¬Bass.

Bialek W, Botstein D (2004). Introductory Science and Mathematics Education for 21st Century Biol., Sci., 303: 788-790

Boud D (1985). Problem-based learning in perspective. In D. Boud (ed.) Problem-based learning in education for the professions. Sydney: HERDSA, pp. 13–19.

Boud D, Feletti G (1991). The Challenge of Problem-Based Learning. London: Kogan Page.

Cowdroy RM (1994). Concepts, constructs and insights: the essence of problem-based learning. In S.E. Chen, R.M. Cowdroy, A.J. Kingsland & M.J. Ostwald (eds.) Reflections on Problem-Based Learning. Australian PBL Network, Sydney.D.R. Paulson, J.L.Faust, Active Learning for the College Classroom. http://chemistry.calstatela.edu/Chem&BioChem/active/main.htm

Finucan PM, Johnson SM, Prideaux DJ (1998). Problem – based learning: It's rationale and efficacy. Retrieved March8,2005. Med. J. Australia (MJA). 168:445¬448from http://www.mja.com.au

Hannan A (2000). Changing Higher Education: Teaching, Learning and Institutional Cultures, A Discussion Paper for the Scottish Forum on Lifelong Learning, Education online, http://www.leeds.ac.uk/educol/documents/00001855.htm

Naoum BK, Rabut C, Wertz V (2008). PBL in Mathematics. Proceedings of the Problem Based Learning (PBL 2008) conference.

Perrenet JC, Bouhuijs PAJ, Smits JGMM (2000). The suitability of problem-based learning for engineering education: theory and practice. Teaching in higher education (5)3: 345-358

Poikela E (2003). Context-based assessment. Refereed proceedings of the 3rd Inter¬national Conference of Researching Work and Learning 25–27 July 2003. Tam¬pere, Finland.

Poikela E, Poikela S (1997). Concepts of learning and the implementation of Prob¬lem-based learning. Zeitschrift für Hochschuldidaktik, Special Issue. Problem-based learning: theory, practice and research. Editors F. Eitel & W. Gijselaers. 21(1): 8–22.

Poikela E, Poikela S (2001). Knowledge and Knowing in Problem-Based Learning. Refereed proceedings of 3rd Asia Pacific Conference on PBL, Experience, Empow¬erment and Evidence. University of Newcastle, Australia.

Krivickas RV (2005). Active Learning at Kaunas Unversity of Technology, (UICEE) Global J. Engineer. Educ., (9):1.