Revista EIA, ISSN 1794-1237 Número 14, p. 85-95. Diciembre 2010
Escuela de Ingeniería de Antioquia, Medellín (Colombia)

PROBLEM-BASED LEARNING APPLICATION IN ENGINEERING

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ABSTRACT

Problem-based learning is a pedagogical strategy widely applied in many universities worldwide with the purpose of improving the learning out come of the students who become the center of the process. This paper presents a case report illustrating an experience, its evolving process and subsequent results of a problem-based learning (PBL) application during five semesters in a Process Management and Control course for under graduate programs of Industrial Engineering and Management Engineering in Colombia. The teacher's role and student assessments are critical elements for the evaluation of the PBL implementation process.

KEY WORDS: PBL; Process Management and Control course; students; teacher; assessment.

APLICACIÓN DEL APRENDIZAJE BASADO EN PROBLEMAS EN INGENIERÍA

RESUMEN

El aprendizaje basado en problemas es una estrategia pedagógica ampliamente utilizada en el mundo con el propósito de mejorar el aprendizaje de los estudiantes, quienes se convierten en el centro del proceso. Este artículo presenta el reporte de un caso que ilustra la aplicación, el proceso y sus resultados de aprendizaje basado en problemas (ABP) durante cinco semestres consecutivos en el curso de Gestión y Control de Procesos perteneciente a las carreras de Ingeniería Industrial e Ingeniería Administrativa en Colombia. El papel del profesor y los resultados de los alumnos son elementos críticos en la evaluación del proceso de implementación de ABP.

PALABRAS CLAVE: ABP; curso de Gestión y Control de Procesos; estudiantes; profesor; evaluación.

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Artículo recibido 10-III-2010. Aprobado 23-XI-2010
Discusión abierta hasta junio de 2011

APLICAÇÃO DA APRENDIZAGEM BASEADA EM PROBLEMAS EM ENGENHARIA

RESUMO

A aprendizagem baseada em problemas é uma estratégia pedagógica amplamente utilizada no mundo, com o objetivo de melhorar a aprendizagem dos alunos, que se tornam o centro do processo. Este artigo apresenta um relatório de um caso que ilustra a aplicação, o processo e os resultados da aprendizagem baseada em problemas (ABP) durante cinco semestres consecutivos no curso de Gestão e Controle de Processos pertencente às carreiras de Engenharia Industrial e Engenharia Administrativa na Colômbia. O papel do professor e os resultados dos alunos são elementos críticos na avaliação do processo de implementação da PBL.

PALAVRAS-CÓDIGO: ABP; curso de Gestão e Controle de Processos; alunos; professores; avaliação.

1. INTRODUCTION

Problem-based learning (PBL) is a pedagogical strategy centered in the student who learns by facing real life problems and working in teams, making the students responsible for their own learning and changing the role of the teacher to become a facilitator. It should be clear that PBL is not about solving problems but learning by doing as the purpose of PBL is to work in a de-centered teacher environment, promoting students participation in decision making about their learning trajectories. Of course at the end students and teachers develop skills to understand and solve real problems, but not as the main purpose of PBL.

PBL has been used for decades, mainly in medicine and law education worldwide but it has also spread its application to other fields such as natural sciences, social and applied sciences. It is possible to find successful PBL implementations in engineering education in different countries throughout the world, such as Australia, Canada, Denmark, Mexico and USA (Du, de Graaff and Kolmos, 2009), in South America such as Argentina, Peru, Brazil (Azevedo da Silveira, *et al*., 2009), and finally in Colombia at the Universidad Nacional de Colombia and Universidad de Antioquia (Restrepo, 2005).

This report presents the results of a problem-based learning experience in a Process Management and Control course for Industrial and Management Engineering programs at Escuela de Ingeniería de Antioquia, EIA, located in Envigado, Colombia. In other words, this work is a case study with students on their third year period with no previous experience on PBL. This curricular experience was designed based on PBL for professional action as it was "focused on a real life situation that requires an effective practical resolution" (Savin-Baden, 2000).

This paper describes the process followed from the second semester of 2007 until the second semester of 2009 for total of 118 students, continuing with a summary of lessons learnt and ending with conclusions and further improvements.

The experience has been rewarding for the students from the point of view of their learning experience but far greater for the teacher as the advantages of the application of the PBL model in the classroom could be identified.

Finally, the application of PBL has been evolving through the five semesters of the course as important changes have been implemented in order to improve the usage of the methodology in the classroom. However, improvements should continue mainly in the teachers role and in students' assessment.

2. BACKGROUND

How can I get my students to think? is a question asked by many faculties, regardless of their disciplines. Problem Based Learning (PBL) is an instructional method that challenges students to

> "learn to learn", working cooperatively in groups to seek solutions to real world problems. These problems are used to engage students' curiosity and initiate learning the subject matter. PBL prepares students to think critically and analytically, and to find and use appropriate learning resources. (Duch, 2008).

A significant number of universities, schools, and institutions have been attempting to implement changes in learning and teaching philosophies and methodologies for engineering, looking for an important objective which is very clear for engineering teaching and learning process: the application of the theory in order to solve real world problems (Dowell, Bruner and McTague, 1994). This concern can be seen in many publications and universities in the world, and is well explained in an article published in the Australasian Journal of Engineering Education which states:

> In recent years studies have been conducted in many countries to determine the technical and personal abilities required of engineers by today's industry. These studies have indicated some key concerns. Today's engineering graduates need to have strong communication and teamwork skills, but they don't. They need to have a broader perspective of the issues that concern their profession such as social, environmental and economic issues, but they haven't. Finally, they are graduating with good knowledge of fundamental engineering science and digital and computer literacy, but they don't know how to apply that in practice. These studies have informed reviews of engineering education conducted in several countries and have had a major influence on the revision of national accreditation criteria for engineering programs in countries such as the USA, UK and Australia (Mills and Treagust, 2003).

These attempts have been successful in some cases but, even though there is a general conviction that more changes are required, there are significant barriers to do so, mainly related to internal cultural issues of the universities as well as teachers' resistance as they are not prepared for the change, due mainly to their fear of losing control or getting lower performance evaluation outcomes.

The learning theories have developed significantly over the years and there are many serious conclusions on why and how a human being learns, of which some of the most important are summarized below.

Jean Piaget with his stages of cognitive development has been one of the most studied, discussed and followed.

Catherine A. Hansman said: "In my view, it is imperative that adult educators understand that learning can take place in many settings and therefore design programs that incorporate tools, context, and social interactions with others" (Hansman, 2001).

On the other hand, Etienne Wenger (1998) defends social learning using his concept of communities of practice.

Based on the above concepts and accepting that learning process of a human being occurs inside himself and the primary outcome a teacher can expect is a sharing of understanding, universities have to make all possible efforts to facilitate this process which means that the development of new practices is necessary in order to improve the learning process of all students, allowing them to develop generic and subject specific competences required in a globalized working environment.

2.1 PBL approach

Literature shows a good amount of attempts to define PBL but this work follows Kolmos in her understanding that refers PBL to theory, models and practice (Kolmos, 2002, p. 64; De Graaf and Kolmos, 2003, p. 657); as follows:

- *Theory*. Central theoretical learning principles, which primarily include cognitive learning theories, such us constructivism and experiential learning, social learning theories and situated learning theories.
- *Models*. Concrete educational models with a foundation of problem-based learning prin-

ciples, going from one-day-one-problem at Republic Polytechnic in Singapore, two weeks one problem at medical studies in McMaster and Maastricht Universities, and project organized learning of one semester at Aalborg University.

- *Practice*. Different practices within guidelines of traditional educational models.

In terms of theories, there has not been a dominant one in the development of the problem-based learning model, since it has been developed first and foremost on the basis of practice. According to de Graff and Kolmos (2003, p. 658), the following are typical learning principles mentioned by the scholars on PBL:

- Problem-based learning because the problem is the starting point of the learning process.
- Participant-directed learning processes as the students are the owners of their learning, meaning, therefore, that it is centered in the student.
- Experience learning considering that the students use their own particular experiences and interests.
- Activity-based learning because PBL requires that the students research, make decisions and also write about them.
- Inter-disciplinary learning as the solution of the problem goes beyond the boundaries of the individual subject.
- Exemplary practice (learning) as the results has to show the benefits for solving the specific problem.
- Group-based learning bearing in mind that the majority of the learning process happens in groups of students who learn together.

2.2 Role of the teacher in PBL

The most common approach to the role of the teacher in PBL environments is that of a facilitator, concept coming from the idea of making the work "easy" (facilis in Latin).

"Facilitators are people with the skills to create conditions within which other human beings can, so far as is possible, select and direct their own learning and development" (Gregory, 2002).

Based on the above definition and following Kolmos, facilitator seems to be the correct concept suggesting openness towards the student and contains a more balanced power relationship between teacher and student". It is also clear that the facilitator promotes a social learning process helping the students to act in cooperation through permanent communication among them (Echavarria, Noriega and Ommestrup, 2008).

2.3 Assessment of the students

Successful assessment methods in PBL that could be applicable at EIA are described by Macdonald and Savin-Baden (2004) and are as follows (Echavarria, Noriega and Ommestrup, 2008):

a. *Group presentations*. A group of individuals present a realistic problem, solved within a curriculum context. These presentations can be difficult to assess, as it is not easy to define a clear goal of what is being assessed within the presentation.

b. *Individual presentations*. The problem to be faced is presented by the individual that has researched the needed knowledge.

c. *Case-based individual report*. The individual solution of a case problem is presented in the form of a written report.

d. *Portfolios*. These have to be designed to fit the needed outcome for the subject. Individuals should use these to elaborate, reflect and make conclusions on the content of the portfolio. This portfolio has to be brief and critical towards the knowledge learned.

e. *Triple jump* (Painvin *et al.*, 1979; Powles, *et al.*, 1981). This assessment type can be resource heavy as it requires three steps. The first step is to discuss the needed learning outcome to solve a given problem. The next step is to research the material needed and to discuss findings. The last

step is then to evaluate the acquired skills within the problem solved, the gained knowledge and the self-directed learning.

f. *Self-assessment*. As introduced by McMaster University in the 60s has shown good results in a problem based learning environment, but students must be carefully trained. Self-assessment allows students to think more carefully about what they do and do not know, and what they additionally need to know to accomplish certain tasks.

g. *Peer assessment and feedback*. This provides a team-based replica as used in the professional work-force. This process is usable in all aspects of an evolutionary process, is an important aspect of a PBL learning environment and is a valuable skill for their future life-long learning.

h. *Reflective reports*. Have to be open and honest towards the learning outcome and should reflect feedback to and from peers; and it is also a communication skill needed later in one's life-long learning.

i. *Problem-based examinations*. It should reflect the type of learning activitiest hat has been experienced.

3. RELATED WORKS

There have been interesting implementations of PBL in engineering education in diverse locations in the whole world such as:

- *Brazil*. Applications of PBL in engineering started 13 years ago and the main barrier has been teacher resistance as engineer professors do not normally have pedagogical education and, although its application has been growing, there is still a long path to follow. (Azevedo da Silveira *et al.*, 2009).
- *Australia*. PBL assessment in first year of electrical and electronic engineering at Victoria University was carried out using learning portfolio for group assessment which describes the students work and its progress in a detailed manner emphasizing on the students' best work and efforts. (Stojcevski and Du, 2009).
- *Denmark*. The benefits of group over individual assessment have been clearly identified after a research carried out at Aalborg University, Denmark showing that "the majority of respondents found that the individual project exam tests a limited range of skills compared to group assessment" (Holgaard and Kolmos, 2009).

4. EXPERIMENT APPROACH AT EIA

This experience was done using the PBL model as described by Anette Kolmos in her 2002 lecture about PBL roots and traditions: problem as a starting point, teacher as a facilitator, interdisciplinary (engineering, management and finance), exemplary, participant oriented and group exam (Kolmos, 2002).

However, it could be said that the method applied is a mixture of problem-based learning and project organized learning as the base for the work includes a problem in the first area of the subject as detailed on table 1 and a full case in the second area of the subject also shown on table 1 which covers different parts and /or problems of an enterprise: customer, finance, internal processes, also learning and growth perspectives as required by the subject for which the method was applied. Therefore, if the comparison by Grunefeld and Silén (2000) is used, the problem or task assigned is more related to their project definition as the students have to "analyze the situation and come up with several alternative solutions" (Grunefeld and Silén, 2000), although the length is closer to problem-based.

Furthermore, and as one authority, Joe Oakey, described by some as "the father of Project-Based Learning in California" puts it…

> Why should we care what we call it? Are the two the same? If we can develop a meaningful way for anyone, any age, to be challenged and to learn useful skills and knowledge as they answer the challenge, why should we care if it is called project-based, problem-based, or circus-based?

> We should be expending our energy on more useful questions. (Oakey, 1998).

5. DESCRIPTION OF METHOD

The evolution of the implementation of PBL through the five semesters, since the second semester of 2007 can be seen in table 1 which shows the different methodologies applied in the five main areas of the subject. The areas where PBL was applied are number 2 and 4, which can be considered as the key of the whole subject. The main characteristics of the learning process on these two areas are that the students learn the concepts of the theory through the solution of problems and cases.

Table 1 shows that for area number 2 "Process" the semesters 2007-II, 2008-I and 2008-II (columns 2, 3 and 4 of the table) included investigation of an enterprise to look for the application of the theory in the real life but in later semesters, during 2009 (columns 5 and 6 of the table), the work and the learning process was developed on a more unsolved and ambiguous atmosphere: problem or case.

It could be said that in the last two semesters of the 2009, the problems assigned tend to be more unstructured type based on Bruner's definition (Bruner, 1973) than in the first semesters as described in the above paragraph.

Table 1. History of the teaching methodologies applied in Process Management and Control

MAIN AREAS OF THE SUBJECT		2007 - II	2008 - I	2008 - II	2009 - I	2009 - II
1.	INTRODUCTION	Teacher lecture and readings	Teacher lecture and readings	Teacher lecture and readings	Teacher lecture and readings	Teacher lecture and readings
2.	PROCESS: basic concepts, analysis and flow charts	Enterprise investigation	Enterprise investigation	Enterprise investigation	One case per team.	One problem assigned per team.
3.	Basic tools for improvement and quality management systems. ISO.	Workshop and teacher lecture	Workshop and teacher lecture	Workshop and teacher lecture	Workshop and teacher lecture	Workshop and teacher lecture
4.	STRATEGY MAPS and BALANCED SCORECARD (BSC)	One case for the class split the work per teams and perspectives	One case for the class split the work per teams and perspectives	One case for the class split the work per teams and perspectives	One case per team, same as the one for Process	One case per team.

The work performed each semester can be described as follows. The teacher assigns the problem or the case study to a team of students, giving some indications of the general theoretical concepts as well as the bibliography required to develop the work and learn the concepts. The students started to solve the problem or the case using the bibliography supplied. The learning process of the students complies with the principal characteristics of PBL through problem solving for real life conditions and working in teams.

The only element that is not fully present is the interdisciplinary as the students belong to the same disciplines, although they do cover different situations, areas and companies of a variety of economic sectors.

Analyzing deeper into the PBL application to areas 2 and 4, the following PBL principles were applied to each of them:

- Area 2. PROCESS MANAGEMENT. During the first three semesters (2007-II, 2008-I and 2008-II), the students were asked to see the application of the theory in a company which means that the main principles (as previously described in the PBL approach) were: participant-directed learning process, and group-based learning as the students were asked to investigate the process management implementation in a company, working in teams.

  Moreover, during the first semester of 2009 the students faced a structured real life case which means that the principles applied were as follows:

  — Problem-based learning. They have to understand and develop strategies to solve a case, learning the theory at the same time.
  — Participant-directed learning process. The learning was directed to the students.
  — Group-based learning. The work was carried out in teams.

  Finally, during the second semester of 2009, a company's process was assigned to the students and they had to develop their own case which meant that all principles described in the PBL approach were applied:

  — Problem-based learning
  — Participant-directed learning process
  — Experience learning
  — Activity-based learning
  — Inter-disciplinary learning
  — Exemplary practice (learning)
  — Group-based learning

  The teacher's role as a facilitator was not always possible due mainly to the lack of experience that the students had on this type of methodology. They kept asking for final answers and not just for guidance and felt a certain degree of frustration when they did not get a solution from the teacher. Maybe it happened as well because teacher centered the target in solving the problem and not in the quality of the learning experiences.

- Area 4. STRATEGY MAPS and BALANCED SCORE CARDS. During the five semesters of the subject, the same methodology was applied using a case from Harvard Business School, but applying PBL instead of learning by the case method because the students were asked to solve the case but learning the theory at the same time, which meant the application of all PBL principles (as previously described in the PBL approach): problem-based learning, participant-directed learning process, experience learning, activity-based learning, inter-disciplinary learning, exemplary practice (learning) and group-based learning.

The teacher's role was mainly that of a facilitator in most areas although due to the lack of experience by the students in the methodology, there were moments when they look for more support from the teacher.

Table 2 shows the different assessment methods applied to areas 2 and 4, and its corresponding classifications according to Macdonald and Savin-Baden 2004) suggestions for students' assessment.

Table 2. Assessment types per semester

Type of assessment	2007-II	2008-I	2008-II	2009-I	2009-II
Case-based individual report	Area 2: One written report about team work to learn process management. Enterprise	Area 2: One written report about team work to learn process management. Enterprise	Area 2: One written report about team work to learn process management. Enterprise	Area 2: One written report about team work to learn process management. Case	Area 2: Three written reports about team work to learn process management. Problem assigned
Group presentation	Area 2: Oral presentation about team work to learn process management. Enterprise	Area 2: Oral presentation about team work to learn process management. Enterprise	Area 2: Oral presentation about team work to learn process management. Enterprise	Area 2: Oral exam about team work to learn process management, including theoretical concepts	Area 2: Oral exam about team work to learn process management, including theoretical concepts
Case-based individual report	Area 4: One written report about team work to learn strategy maps and BSC. Case	Area 4: One written report about team work to learn strategy maps and BSC. Case	Area 4: One written report about team work to learn strategy maps and BSC. Case	Area 4: One written report about team work to learn strategy maps and BSC. Case	Area 4: One written report about team work to learn strategy maps and BSC. Case
Group presentations				Area 4: Oral exam about team work to learn strategy maps and BSC, including theoretical concepts	Area 4: Oral exam about team work to learn strategy maps and BSC, including theoretical concepts

6. SIGNIFICANT OUTCOMES

Through the implementation of PBL, the level of learning of the students, as per their own perception according to the answers to EIA standard evaluation of teachers, has been higher when comparing with other subject oriented by the same teacher, but applying a different pedagogical methodology. There is only one exception in 2008-I when it has been almost equal as it can be seen in the table 3 comparing the two subjects: General Management (GM) and Process Management and Control (PMC), both with the same teacher as previously stated, but with different learning and teaching methods. On the one hand, for GM the methodology applied was basically traditional which includes teacher lectures and some workshops and class exercises as the only active learning elements. On the other hand, PBL was applied to the PMC subject.

The final assessments of the students also showed good performance in all the elements, but the two key ones are:

- Oral exams. The last two sessions of both areas 2 and 4 as previously described were spent on a short oral/group exam in order to review theory learnt. These oral exams were also based on the written summary sent by the students in advance and it was carried out by teams, asking general questions and at least one per person.

Table 3. Comparison of learning levels between GM (General Management) and PMC (Process Management and Control).Source: EIA surveys for students´ evaluation of the teacher

Level learning	2007 - II		2008 - I		2008 - II		2009 - I	
	GM	PMC	GM	PMC	GM	PMC	GM	PMC
High (% of students)	50	89	65	60	36	50	70	87
Medium (% of students)	39	11	35	40	55	38	30	13
Low (% of students)	11	0	0	0	9	6	0	0

This type of assessment is based on the PBL theory which says that

> The purpose of the defense and the following discussion is to examine the knowledge possessed by the individual student about the project and the connected academic disciplines as well as their broad insight and professional knowledge. In the session in which the report is presented and defended, the members of the project group are examined in the project courses in connection with the examination of the report (Aalborg University, 2007).

- Additionally, the students were able to apply the knowledge in the final written exam at the end of the semester.

7. DISCUSSION

There are important elements of the process that should be evaluated such as key success factor as well as difficulties found**.**

7.1 Key Success Factor

The students have been trained in advance on the methodology itself in order to achieve that all students have clear understanding that «The aim of the project work is "learning by doing" or "action learning"» (Aalborg University, 2007). This is also fully explained in description of PBL in that university: "… and the basic skills for carrying out problem-oriented project work are trained" (Aalborg University, 2007).

7.2 Difficulties found

Students are not used to find, read, and learn the theory required for solving the problem by them and they feel uncomfortable in many occasions.

Participation of the students in each of the teams was not at the same level as some were totally engaged but others, at least one per team, were occasionally distracted.

The training of the teacher as a facilitator, although improving every semester, has not been sufficient. Thus, it is not easy to change "the traditional role of the teacher from: Lord at the lectern, to coach on the side"(Aalborg University, 2007).

8. LESSONS LEARNT

The aspects which went really well were the learning outcome and the student's perception according to their answers to EIA standard evaluation of teachers carried out every semester.

The aspects which have to be improved are the project description and review before starting and the teacher's role to act as advisor and facilitator using information questions: why, how, what and where, but also involving all the students in the discussions.

Some team member's behavior should also be improved as the team work competence in the students is limited and not developed enough in Colombian traditional educational system on which individual assessment represents the key element for evaluation.

Another important aspect to be improved is the assessment of the students as self and peer assessments have not been applied and both are considered key elements of any PBL application.

9. CONCLUSIONS

This paper shows a relatively successful implementation on the most critical area of any educational strategy that is the learning outcome of the students.

Therefore, experience results have been rewarding as the learning objective of the subject has been achieved and the students seem to have a better learning process, taking into account that the learning process and activities were focused on the learner.

The good results reconfirm that EIA students as well as most people learn more from social interaction and context based added to practical application which are the basic concepts of PBL.

10. FUTURE WORK AND FURTHER IMPROVEMENTS

The PBL training to students should be deeper as they are not used to be responsible for their own learning.

The teacher's role as a facilitator needs to be more developed as the temptation to give solutions is always present.

The assessment process should change significantly in order to examine the project itself as well as the team acquired knowledge and involvement because final written and oral evaluations were mainly related to the project solving, but did not include a sufficient evaluation of the theoretical knowledge acquired by the students.

The assessment of the students for areas 2 and 4 should include self and peer assessment as both types correspond directly to PBL.

Furthermore, it could be recommendable to evaluate a wider and deeper change to PBL covering the entire curriculum as other universities have done.

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