A Problem-based Learning Experience in Engineering Education

Ivete Ana Schmitz Booth[1], Mariluza Zucco Rizzon[1,2], Valquíria Villas-Boas[1]

[1] Graduate Program in Science and Mathematics Teaching, University of Caxias do Sul, Caxias do Sul, Brazil
[2] Colégio São José Caxias, Caxias do Sul, RS, Brazil

Email: iasbooth@gmail.com, mariluzazr@gmail.com, vvillasboas@gmail.com

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Abstract

This paper reports a Problem Based Learning (PBL) experience, held in the Basic Chemistry and Experimental course of the Engineering programs at the University of Caxias do Sul, involving problems related to chemical reactions that occur in daily life. The experiment was structured according to the "Seven Steps of PBL Implementation". The data were collected using two instruments, a pre-test and a post-test on topics of interest with the objective of evaluating students' learning through the PBL method, and an instrument that consisted of an open question in which students were asked to describe the main characteristics of their classes with the Traditional Teaching Model and the characteristics of the classes that used the PBL method. The results of the pre and post-test show the contribution of PBL to the occurrence of a conceptual evolution on chemical reactions. As for the verbalizations about the characteristics of the Traditional Teaching Model and the PBL, the results show that students understand the disadvantages of teaching in the traditional model and the advantages of learning in an environment conceived through the foundations of PBL. The statements show that PBL favours the development of complex skills such as questioning and teamwork, and that decision-making and research are present in the process of learning with PBL. Through these results, it is evident the improvement in the conceptual, procedural and attitudinal learning of the students who participated in the classes with the PBL method in function of better grades and in the development of more complex skills. We know that adequate professional performance goes far beyond quantitative results and student perceptions. However, these results are encouraging to continue new studies. The experience described and analysed was developed in only one course, but, as in other studies, indicated that PBL is an active learning method that is conducive to the occurrence of a meaningful learning in Engineering Education.

Keywords: Problem Based Learning; Active Learning; Engineering Education; Chemical Reactions.

1 Introduction

In many higher education institutions, the concept of teaching is still synonymous of the presentation of content. In these institutions, teacher's action is centered on offering expository lectures, and students' action on listening to these presentations to accumulate information. These teaching and learning processes generate predominantly mechanical (rote) learning on the part of students. In this context, we look at Engineering undergraduate programs and we see that teaching strategies and methods also need to be adapted to the new globalized reality, because if there is no innovation in teaching and learning processes, hardly, the new professional will dare to innovate in the work environment. In this scenario, it is important to base studies and actions to favor the change of the epistemological and pedagogical model of the teacher. Teachers' and students' conception of teaching and learning, teachers' and students' roles, require in the current scenario a process that creates conditions for the occurrence of lasting learning, establishing relationships between new knowledge and what is already known. Thus, teaching is more than passing information. Teaching is to encourage the student to think, to interpret information and, with that, to produce ways of solving problem situations, interacting with colleagues, analyzing demands, proposing actions, and making decisions.

According to the United Nations Educational, Scientific and Cultural Organization (UNESCO), the main asset of an organization resides in the quality of its human capital (UNESCO, 1998). By analogy, in higher education institutions, the quality of their faculty must pass through epistemological and pedagogical training, as it is through it that the proposals of the program's pedagogical projects are designed. The Law of Guidelines and Bases (Brazil, 1999) for Engineering programs, as well as INOVA Engineering (INOVA, 2006), proposes that its graduates be able to conceive, design, analyze systems, products and processes; plan, supervise, conduct experiments, interpret results, work in multidisciplinary teams, communicate efficiently, assess the economic viability of projects and the impact of engineering activities in the social and environmental context. Given these needs, what teaching strategies and methods have the potential to develop these skills? What aspects of mediation need to be present in learning environments when the focus is on more lasting learning?

Learning environments, which favor such training profile, are characterized in spaces where teachers and students work together to develop skills. Creating conditions through a sequence of activities that aim to train the engineer as a creative and innovative professional, and that can transpose and develop new knowledge to deal appropriately with reality is essential. Teaching and learning processes, consistent with this trend, need to be increasingly focused on students' actions with situations that favor interaction, collaboration, exchange of knowledge and the development of meaningful learning (Ausubel, 2003).

Learning environments conceived using the Problem Based Learning (PBL) method can be an alternative for the teacher who believes that it is necessary to break with the traditional teaching model where the student learns by listening and the teacher teaches by talking. PBL is an active learning method, centered on the student, which aims to get him to learn about the subject in the context of real, complex and multifaceted problems (Graaff & Kolmos, 2007). According to Chen, Kolmos & Du (2021), during the last 40 years, problem- and project-based learning (PBL) has been widely adopted in Engineering Education because of its expected effectiveness in developing students' professional knowledge and transferable skills.

Working as a team, students can identify what they already know, what they need to know and how and where to access the new information needed to solve the problem. The teacher's role is to facilitate learning, providing appropriate conditions for the process, doing a prior knowledge survey, providing the appropriate resources, and conducting class discussions, as well as planning student assessments. PBL differs from conventional educational methods especially because it has as its main objective the meaningful learning of the student who is an active subject in this process. Its purpose is to enhance the development of essential skills for the success of the future professional (Booth, Sauer & Villas-Boas, 2016). In 21st century work environments, success requires more than knowledge and basic skills. With PBL, students not only understand content more deeply, but also learn to take responsibility, build trust, solve problems, work collaboratively, communicate ideas, be innovative and creative (Savin-Baden & Howell- Major, 2004).

This paper reports a PBL experience carried out in the Basic and Experimental Chemistry course of the Engineering programs at the University of Caxias do Sul (UCS), in the state of Rio Grande do Sul, Brazil, involving problems related to chemical reactions that occur in everyday life. The following topics are presented in this article: the teaching and learning context in which the experience was developed, the methodology for implementing the PBL method, the results and some final considerations.

2 The Teaching and Learning Context

Working with problematic situations has always been part of the activities of a group of teachers in the area of Exact Sciences and Engineering at UCS. However, more precisely in the period from 2010 to 2014, this group of teachers started the development of a project entitled "UCS-PROMOPETRO: New Challenges for the Engineer of the Future (PETROFUT)" with financial support from FINEP, whose main purpose was to strengthen teaching science and awakening interest in young people for careers in the STEM area (Villas-Boas et al, 2016). In the development of the activities of this project, the method used was Problem Based Learning (PBL), in order to contemplate activities that established connections between the basic knowledge of the Exact and Natural Sciences at high school level and practical applications of the technological areas that had as objective the solution of real problems in the scope of engineering services and industrial activities, including those focused on environmental issues. To this end, the group of teachers studied all aspects of PBL for six months and developed workshops based on this method. This experience and a faculty training in Project-based Learning carried out at UCS in 2012 by specialists from the University of Minho were fundamental for PBL to become part of the planning of some courses of UCS Engineering programs.

UCS Exact Sciences and Engineering area offers 12 Engineering courses (Environmental, Automotive, Civil, Food, Computer, Control and Automation, Materials, Production, Electrical, Mechanics and Chemistry) and has over 3000 students. Most of these students are part-time students and work in the industries in the region. Since they are already employed, many of them are just looking for an Engineering degree.

Combined with this, a significant number of UCS students did not have a good background in Science and Mathematics in high school, which leads them to perform poorly in basic subjects and, consequently, leads many of them to drop out of the program. In this context, the use of an active learning method in the Basic and Experimental Chemistry course was presented as an alternative that could bring many positive results for the learning of these students, including influencing the change in their study habits.

This work was developed with a group of the Basic and Experimental Chemistry course within the Engineering programs at UCS during the first semester of the year 2016. This course is part of the set of courses of the second semester of the Engineering programs. The group, named class A, was composed of twenty-four students, aged 19 to 22 years. Class A students experienced the development of concepts about chemical reactions through the application of the PBL method.

The application of PBL involved problems related to chemical reactions that occur in daily life, with an emphasis on chemical reactions between corrosive media and different materials and was developed in 10 meetings in the first semester of 2016. The semester had 21 meetings of 4 hours of class.

Class A students were divided into teams of 4 students where they took on different roles (leader, secretary and team members). In addition to the course's teacher, a Physics teacher and a master's student in the Graduate Program in Science and Mathematics Teaching, in the field of Biology, also acted as tutors.

3 Method Implementation

Considering the many advantages of using PBL in Engineering courses and programs, notably favoring the integration of knowledge, autonomous learning, collaborative learning, among others, the teacher of the Basic and Experimental Chemistry course, opted for the implementation of PBL, with the objective of to motivate, mainly, students of Engineering programs who do not understand the importance of studying Chemistry. In this context, the teacher identified the conceptual and procedural contents to be developed in a learning environment designed using PBL.

3.1 The development steps of the PBL experience

The experience was structured, inspired by the "Seven Steps to PBL" (Albanese & Mitchell, 1993; Barrows & Tamblyn, 1980; Boud & Feletti, 1997), and was applied to class A in the sequence presented below:

Step 1: students examined damaged metal structures, which led them to manifest their prior knowledge. Then, a pre-test on everyday chemical reactions was applied. This step helped in the identification of previous knowledge, accepted or not accepted in the context of the course subjects.

Step 2: a problem was presented to the students, and it was related to a complex real-world problem in order to mobilize students about new knowledge. The problem situation presented is set out below:

Itaipu Binacional Power Plant (https://www.itaipu.gov.br/en) has 20 hydrogenerators with individual rated power of 700 MW. Each hydrogenerator has 37 heat exchangers, 16 of which are air / water exchangers from the stator core. The first evidence of water leakage in one of the hydrogenerators occurred in 1992, on machine 4, followed by another leak in 1993, on machine 15, and the problem is no longer considered an isolated case. In this context, as a team, you must prepare an intervention proposal to avoid future spills in the hydroelectric generators of the Itaipu Binacional Power Plant. The proposal must present actions based on the areas of Physics, Chemistry and Biology, considering the social and environmental contexts.

The students, gathered in teams of 4 components, through discussion, raised questions, identified gaps in knowledge existing in the team and characteristics of the problem that they did not understand.

Step 3: students prioritize learning issues and afterwards planned a work schedule with individual and collective actions to clarify issues of the problem to be investigated.

Step 4: students individually searched answers for the questions to be investigated and the concepts related to their knowledge gaps.

Step 5: students, gathered as a team, explored the questions chosen for studies in order to integrate new knowledge into the real context of the problem. At the end of this step, other relevant issues and aspects of the phenomenon under study were taken up, for the systematization of knowledge supported by the reading of a scientific article, followed by a collaborative activity in teams.

Step 6: students, gathered in teams, presented their solutions to the problem for the large group.

Step 7: students assessed the feasibility of using PBL through two data collection instruments.

3.2 About the pre-tests and the post-tests

Pre- and post-tests were used to validate the knowledge built by students in the course. The pre-test consisted of a set of 10 open questions applied to students in class A, to assess the level of knowledge about the subjects that would be taught. It was also explained that the purpose of the pre and post-test was to assess the knowledge built. In addition, the results of the pre- and post-test comparison aimed to answer the following question: "Did the students achieve the learning outcomes?"

The test questions were developed in line with the objectives of the classes. This criterion ensured visibility to provide evidence and to demonstrate what knowledge students have developed with PBL. The choice for open-ended questions was because they require participants to use their own words to answer or comment on a specific situation. The questions were developed with simple words, without ambiguity and according to the learning outcomes.

The pre and post-test lasted 40 minutes each. The tests were carried out individually, to obtain a more real analysis on the conceptions of each student. The application interval for these instruments was six weeks. During that time, the steps of the PBL described above were developed. The post-test contained the same open questions as the pre-test. A definite criterion was that the pre-test questions were not discussed at the following meetings, nor were any comments made on their resolution.

The analysis performed in the pre and post-test was a quantitative analysis. The distribution of students' grades in each question, both in the pre and post-tests, was verified to assess the learning that occurred. The investigation of the occurrence of conceptual evolution was done through an analysis of the students' answers to the set of open questions.

4 Results

In this section, we will present the results of the pre- and post-tests and some testimonies from students in class A about the teaching-learning method adopted. Believing in the potential of PBL for the acquisition of meaningful knowledge and in the occurrence of a meaningful learning of concepts related to chemical reactions, this investigation sought to highlight possibilities or limitations in the use of the method used.

4.1 Results of the pre-tests and the post-tests

Figure 1 shows the distribution of grades of students in class A, submitted to the pre-test and the post-test. It can be seen in Figure 1 that 70% of the students in class A submitted to the pre-test scored between 1.0 and 4.0 on a scale from 0 to 10.0. Still in Figure 1, it can be seen that 80% of students in class A submitted to the post-test obtained scores between 5.1 and 8.0. The results presented in Figure 1 show the contribution of PBL in the occurrence of conceptual evolution.

Through these results it is evident the improvement in the learning of the students who participated in the classes with the PBL method considering the better grades. We know that academic success goes far beyond the quantitative results obtained in this study, however, these results are encouraging to continue with new studies. As mentioned before, with PBL, students develop important skills as group work, autonomous learning, self-assessment skills, time planning, project work or oral and written expression skills. PBL also improves student motivation, which translates into better academic performance and greater persistence in the study.

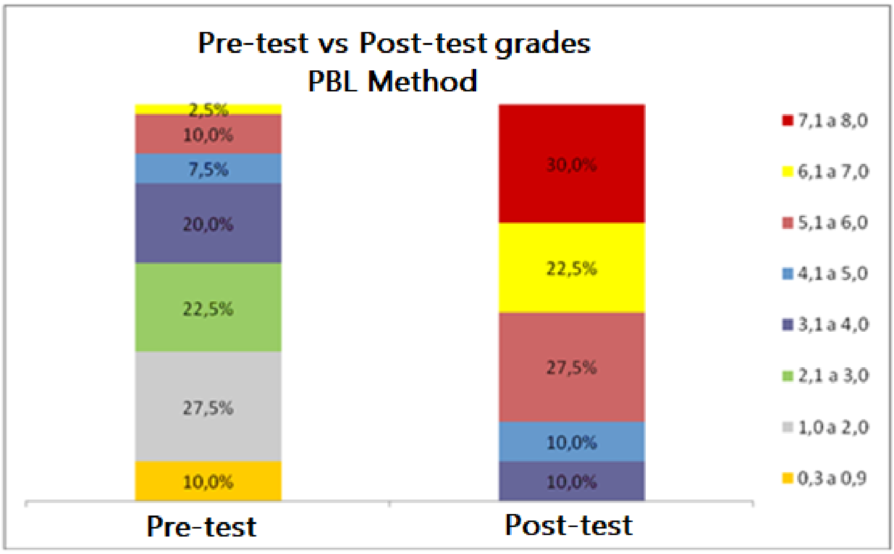

Figure 1. Distribution of Pre-test vs Post-tests grades of students in class A.

4.2 Testimonials from Class A students about their experience with PBL

Class A teams were named E1, E2, E3, E4, E5 and E6. Most student teams evaluated the PBL proposal positively. Highlighted some verbalizations of students from teams E2, E3, E4 and E6.

The students of the E2 team pointed out that "this strategy made the meetings active, the work of one colleague complemented the work of the other, with the exception of a colleague who was very slow". They also stressed that "we learned to research in reliable sources and to present the productions with less nervousness".

The students of the E3 team pointed out that "learning was built through the collaboration of everyone, with many discussions, help from colleagues and organization of the team. The team was advancing in the records and in the communication during the process".

The students of the E4 team stressed that "we were very involved in the activities, so the class was not monotonous, it did not make us sleep", and that "we also study in the classroom itself and demanded the tasks of colleagues and also helped some colleagues".

The students of the E6 team described that this method "... favored the ability to know different sources of information about the necessary concepts, and during discussions in the team we better understand these concepts to apply them in the problem situation". They also stressed that "two colleagues were hardly involved in the activities, but the others were committed to the team, which allowed for a good interaction for the development of professional skills and the understanding of concepts".

The students from teams E1 and E5 highlighted that "... we had a lot of difficulties in this process ...." ... the main difficulties were the lack of initiative and of a ''head to pilot the activities (leader), difficulties in plan work, make decisions, because one waited for the other"...

The students of the E5 team also pointed out that "contact with other teams was especially important for us, gave us more disposition, initiative", and commented among themselves that "... if the other teams were doing it, we will be able to do it too" and so "The process was happening in the team with more guidance from the teacher and tutors".

In this context, it is possible to affirm that the PBL method was well accepted by most students in class A, and that PBL favored the development of skills for: working in teams, researching, problematizing, planning, deciding, recording data, systematizing information, analyzing, synthesizing, building arguments and for the development of oral and written communication.

4.3 Students comparing PBL with the Traditional Teaching Model

Students were asked to evaluate the main characteristics of the two different methods (Traditional Teaching Model and classes that used the PBL method) and their potential to promote learning and the development of skills and attitudes. The tabulation of the verbalizations of students in Class A is shown in Table 1 below. From the verbalizations presented in Table 1, it can be seen that the students presented opinions that were quite consistent with the characteristics of each of the teaching methods. These results indicate that students understand the disadvantages of teaching in the Traditional Teaching Model and the advantages of learning in an environment designed using PBL, where they must assume responsibilities, build trust, solve problems, work collaboratively, communicate ideas, to be innovative and creative, and to work in teams.

Table 1. Student verbalizations about the characteristics of classes in the Traditional Teaching Model and of classes with the PBL method.

Classes in the Traditional Model	Classes with the PBL method	
Predominance of teachers' speech (15)	Activity is motivating, it is related to a real situation (24)	Information search (24)
Student work is individual (11)	Work related to future professional practice (17)	Decision making (20)
The study is with a book or handout (13)	Need to adapt to group work and to manage time (12)	Selection and outline of reliable information sources (24)
The activity in the classes is listening, copying, looking at slides (15)	Need to adapt to group work and to manage time (12)	Planning the investigation and studies of each component of the group (24)
Often, we do not know why we are studying that content (18)	The teacher does not teach, he guides the work (14)	Responsibility for results (13)
There is a repetition of the book's content without discussion and without application (22)	Working with the different components of the team was difficult (7)	Constant search for information, guidance, collection, selection and systematization of knowledge (24)
The tests are to classify, to grade. (24)	Teamwork was carried out with a schedule of activities (8)	Presence of seminars with the evaluation of colleagues and the teacher (18)
Monotonous lesson. Just study what they talk about and you pass (14)	Elaboration of questions and explanation of the questions that the problem situation needed (14)	Interpret data, make conclusions (5)
Teacher speaks, student writes down, studies and ready (12)	Survey of hypotheses and possible explanations about the problem (10)	

Note: the number in parentheses corresponds to the number of students who performed such verbalization.

5 Final Remarks

It is well known that the development of learning also occurs in the long term, especially through the student's ability to mobilize knowledge and apply it in new everyday situations. However, the results obtained indicate that it is of fundamental importance to alert to the need of learning other competences, such as scientific reasoning, self-regulation, and autonomy in the learning process (Vasconcelos, 2012). These characteristics are described in the students' verbalizations in Table 1, when they describe the characteristics of the classes with the PBL method. From the above, this study presents several evidences that the adoption of active learning strategies and methods in Engineering Education offers Engineering students better conditions for the development of structuring skills and competences so that they act properly in their professional field. Thus, this study is yet another example that shows that problem-based learning (PBL) has the potential to increase problem-solving skills, independent learning, and the ability to develop teamwork (PRINCE et al., 2005).

In addition to these aspects, in Table 1, verbalizations related to the characteristics of raising questions, being a motivating method, among others, are present. These testimonies show that PBL favors the development of questioning skills and that decision making and investigation are present in the process of learning. PBL presents students with the opportunity to deal with processes that tend to develop autonomy, decision making, and teamwork. In a learning environment conceived using PBL, students are the agents of their learning, authors of the construction of their knowledge through various collective and investigative actions. Sadeh and Zion (2009), point out that PBL involves processes that promote the development of critical and reflective thinking about the process, also involving emotional aspects, such as curiosity.

The PBL experience carried out in the Basic and Experimental Chemistry course proved to be a learning environment with great potential in the context of Engineering Education. The experience described and analyzed was developed in only one course, but, as in other studies, it indicated that PBL is an active learning method that is conducive to the occurrence of meaningful learning. This study is not a complete analysis of the analyzed phenomenon, but it has great potential to promote the occurrence of meaningful learning in Engineering Education.

6 References

Albanese, M. A., & Mitchell, S. (1993). *Problem-based learning: A review of literature on its outcomes and implementation issues*. Academic Medicine, 68(1), 52–81.

Ausubel, D. P. (2003) *Aquisição e retenção de conhecimentos: uma perspectiva cognitiva*. Lisboa: Plátano.

Barrows, H. S., & Tamblyn, R. M. (1980). *Problem-based learning: An approach to medical education.* Heidelberg: Springer.

Boud, D., & Feletti, G. I. (1997). Changing problem-based learning. Introduction to the second edition. In D. Boud & G. I. Feletti (Eds.), *The challenge of problem-based learning*. Milton Park: Routledge, p. 1–14).

Booth, I. A. S.; Sauer, L. Z.; Villas-Boas, V. (2016). Aprendizagem baseada em problemas: um método de aprendizagem ativa. In: Valquíria Villas-Boas; José Arthur Martins; Odilon Giovannini; Laurete Zanol Sauer, Ivete Ana Schmitz Booth. (Org.). *Aprendizagem baseada em problemas: estudantes de ensino médio atuando em contextos de ciência e tecnologia*. 1ed. Brasília: ABENGE, v. 1, p. 35-63.

Brazil. Diretrizes curriculares para os cursos de engenharia. Anteprojeto de Resolução. Brasília, DF, 5 de maio 1999.

Chen, J., Kolmos, A., & Du, X. (2021). Forms of implementation and challenges of PBL in engineering education: a review of literature. *European Journal of Engineering Education*, *46*(1), 90-115.

Graaff, E. d., & Kolmos, A. (Eds.). (2007). *Management of Change: Implementation of Problem-Based and Project-Based Learning in Engineering*. Roterdam: Sense Publishers.

INOVA Engenharia: *Propostas para a modernização da educação em engenharia no Brasil*. Brasília: IEL.NC/SENAI.DN, 103 p.; ISBN 85-87257-21-8, 2006.

Prince, K. J. A. H., Van Eijs, P. W. L. J., Boshuizen, H. P. A., Van Der Vleuten, C. P. M, & Scherpbier, A. J. J. A. (2005). General competencies of problem-based learning (PBL) and non-PBL graduates. *Medical education*, *39*(4), 394-401.

Sadeh, I., & Zion, M. (2009). The development of dynamic inquiry performances within an open inquiry setting: A comparison to guided inquiry setting. *Journal of Research in Science Teaching*, *46*(10), 1137-1160.

Savin-Baden, M.; Howell-Major, C. (2004). *Foundations of Problem-based Learning*. McGraw-Hill Education, New York.

UNESCO. La Educación Superior en el Siglo XXI: Visión y acción, Documento de Trabalho, Paris, outubro 1998.

Vasconcelos, C. (2012). Teaching environmental education through PBL: Evaluation of a teaching intervention program. *Research in Science Education*, *42*(2), 219-232.

Villas-Boas, V.; Martins, J. A.; Giovannini, O.; Sauer, L. Z.; Booth, I. A. S. (Eds.). (2016). *Aprendizagem baseada em problemas: estudantes de ensino médio atuando em contextos de ciência e tecnologia*. 1ed. Brasília: ABENGE.