

Active Learning through Problem Based Learning Methodology in Engineering Education

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Abstract - The main objective of this experience lies on the development of positive learning aptitudes on engineering students. The experience presented in this paper has been carried out with the help of the problem-based learning (PBL) methodology. Solutions of medium-high complexity problems by students make them work on the development of different skills. The teaching model turns into a significant and autonomous learning model where students are conscious of their compromise with this process (learning). The obtained results are a starting point to other authors willing to use active learning methodologies within the framework of engineering degrees. Both lecturers and students involved in the experience have done a positive assessment of the methodology.

Index Terms – Active Learning, Competences, Interdisciplinary Education Projects, Problem-Based Learning.

INTRODUCTION

The great technological advances produced in the last years, especially in the sector of information and communications technologies (ICTs), make it necessary to update professional's knowledge in a continuous way.

Learning models based on competences will facilitate the integration of students into the professional world, allowing further integration into the society, where learning is a necessity. In this scenario, a change in teaching methods will be necessary; new methods of work must not be based on teaching (focusing on the lecturer) but in learning (student-centered). The final aim will be learning to learn, as essential step for continuous learning (lifelong learning). This goal is clearly expressed in the declarations of Bologna and Prague [1].

In the field of engineering, the number of work areas will be very extensive and somewhat not much predictable. Engineers are able to work in lots of different designs and projects, management issues, operations, development, sales, etc. For this reason, it will be essential to identify the competences necessary for the forthcoming broad and changing employment context.

SKILLS TO BE DEVELOPED BY STUDENTS

Broadly speaking, competences can be regarded as skills or abilities to understand and use knowledge, solve problems, use tools or technologies, learn in an autonomous way,

research and think with initiative and creativity, communicate, cooperate, and so on.

The design of the university curriculum in terms of skills generates the need to design educational goals beyond a disciplinary content. These goals are linked to intellectual, social and professional demands according to the labor market. Two competences levels can be established: degree generic competences (regarding to transferable skills) to be used on a high number of functions and tasks and specific degree competences, directly related to the occupation.

In this work, we deal with generic competences. This study will be on this form transferable to an extensive number of different degrees.

GENERIC SKILLS

The Spanish Organic Law of Universities in its first article states as a first function of the university "science, technology and culture creation, development, transmission and criticism". In this way, students should develop intellectual, technical or artistic and also social and personal abilities. These skills or competences should foster creativity, problem solving and independent learning throughout their lives [2]. The Tuning project [3] examined the general academic competences for all, proposing 30 competences categorized into three groups: instrumental, interpersonal and systemic. The generic competences specified in the Computer Engineering Degree Guide proposed by ANECA [4] are very similar to those set in the Tuning Project. On this guide the importance of each competence is valued through the analysis of the some surveys results carried out to a several groups of companies, qualified professionals and lecturers. The competences setting are:

- **Instrumental:** analysis and synthesis capacity, planning and organization capacity, oral and written communication in the native language, knowledge of a foreign language, computer knowledge in the field of study, capacity for information management, problem solving, capacity to take decisions.
- **Personal:** teamwork, working in an interdisciplinary team, working in international contexts, interpersonal relations, recognition of diversity and multiculturalism, critical thinking, ethical compromise.
- **Systemic:** self-learning, adapting to new situations, creativity, leadership, knowledge of other cultures and customs, entrepreneurship initiative, motivation for quality, sensitivity to environmental issues.

The specific skills belonging to the degree will complement these generic skills. We deal with only the first group (generic competences). Therefore, we present several aspects to be taken into account to develop instrumental, personal and systemic competences on engineer students. To achieve this aim it will be necessary to use teaching methods based on the student (learning) instead of teaching methods based on lecturer (teaching) [5][6][7].

One of the main methodologies based on the student learning is problem-based learning (PBL). This methodology is the one analyzed and used in this work. According to the Bologna Declaration [8], teaching based on problem solving (in which students have an active role in their learning) allow students to understand better difficult concepts and retain the knowledge acquired for a long period of time. Besides, it allows them to develop the required skills [9] both in today's world and in the European Space for Higher Education (ESHE): continuous learning, autonomy, teamwork, critical thinking, communication and planning skills [10].

It is now felt that PBL is one of the methods for the new models in higher education based on learning [10] [11] being the methodology used in this study.

PROBLEM BASED LEARNING (PBL)

The origin of the problem-based learning goes back to the 60s. Weingarner and Postman (1969) proposed a teaching model that dispensed with lectures and developed the creative capacity of students by raising questions and open problems. These ideas were first applied in the Mc Master University (Canada) and in the School of Medicine of Case Western Reserve University (USA), appearing for the first time the so-called Problem Based Learning (PBL) methodology. The success of this method led to its expansion throughout the world. It was first used in Europe at the University of Maastricht (1974). Now, the methodology is being applied to all its offered degrees. At the same time, during the 70s, the Danish University of Aalborg developed a new method derived from PBL, the project-based learning.

Nowadays, PBL is considered as one of the suitable methods for the new models of higher education based on learning [11]. Then, several schools and universities use PBL as the core of its training strategy [12] [13].

With this methodology, students must assume greater responsibility and freedom of action. They will undertake a process of self-learning (known as "learning to learn"), necessary for solving the problem initially introduced by the lecturer.

At any time, the lecturer will be in charge of ensuring the involvement and motivation of students; he will have to help the students to know the sources they need to consult, as well as to identify difficulties. The figure of lecturer gets a new role: directing the student on the learning process and being a mentor to undertake an active role rather than a facilitator one.

Another important aspect to be considered deals with the used resources. For this kind of methods, classrooms with flexible furniture allowing group meetings are needed. Furthermore, the possibility of using laptop computers in tables would be a good option, because new technologies could be integrated on a natural form as a learning tool. The use of e-learning software will be also useful because it will allow students and tutors to have repositories of documents, communication tools, such as e-mail, forums, etc.

In short, PBL methodology can be summarized in the following "golden rules" [14]:

1. Students must take responsibility for their own learning.
2. Problems/projects have to be presented intentionally unstructured and allowing free interpretations.
3. Learning is not to lead to a specialization of knowledge, but to lead to a wide range of disciplines or subjects.
4. The learning achieved by the students, in the stages of study and independent learning, has to be applied subsequently to the practical problem proposed.
5. It is essential to make a final summary containing all that has been learnt during the process of problem solution. It is necessary to discuss what concepts or principles have been learnt in a suitable way, and what should be strengthened before starting the evaluation process.
6. The evaluation and self-evaluation should be carried out at the end of each problem and at the end of the complete curriculum unit.
7. Individual assessment of students is always done according to the objectives previously proposed.
8. The topics and activities have to be always connected to the real world, and bring values cherished in the social and professional fields.
9. Cooperative teamwork, collaboration, learning and self-responsibility, must be taken as key skills essential to the work.
10. The PBL must be the base of the educational curriculum and not just a part of the educational curriculum.

Next section describes some aspects to be taken into account when an inter-disciplinary experience based on PBL is designed and implemented. These aspects have been established, consolidated and improved from a study carried out in the field of engineering along several years. These aspects may be taken into consideration when a similar experience must be designed. However, the context of the experience may involve an adaptation in a less or in a greatest extent of these recommendations. We present a pilot project carried out within the framework of a Computer Engineering degree.

IMPLEMENTATION OF THE METHODOLOGY

I. General aspects

In the design of an inter-disciplinary (or inter-departmental) PBL experience, the existence of complementarities among

the subjects (those chosen for the experience) is an important issue to be taken into account. The development of the project/problem presented by the lecturer will have to allow students to integrate the contents of all of them.

The Institute of Technology and Superior Studies of Monterrey [15] recommend beginning, in the case of pilot experiences, with students who have already learnt some basic knowledge in the course of the degree. It allows them to start the project at the beginning of the term, because they already have the concepts needed.

The proposed project must have the characteristics of an appropriate problem of PBL. Namely, it must: be relevant and interesting for students, have clear objectives and stages, be complex in the sense of having different solutions, be an interdisciplinary project and present situations close to the professional world. In general, the existence of a small number of students will make easier the implementation of the PBL methodology as a learning method.

The use of a virtual learning platform will be also recommended. It helps to improve both the lecturer-student and lecturer-team interaction using different tools as chat, e-mail, forums, private intranets, etc. It also acts as a repository of information, a common repository to load documents belonging to both sides (students and lecturers). Of course, students must have computers to access to on-line documents and to the virtual learning platform.

It is very suitable and advisable that documentation produced by students is homogeneous, maintaining the same format. Examples of documentation may be: Gantt chart, documents of the meetings (minutes and notifications), final project documentation (analysis, prototype and final product).

In the development of the experience, the main functions of the lecturer will consist of offering the problem/project and providing the basic knowledge of the subject. This provided knowledge will let the development of the self-learning competence by students. He also must have the role of client, evaluating the project and the documentation presented by students. He must also meet with teams on a weekly basis, making a follow-up of them and guiding them in their learning. The lecturer also checks the project advances and the individual student work. After that, lecturers meet with all colleagues involved in the project to carry out the coordination task, a linchpin on the project success.

At this stage, through the implementation of PBL, students will carry out several learning process:

- Knowledge integration: they work on a interdisciplinary project.
- Development of learning skills for the acquisition of new knowledge usually referred as "learning to learn."
- Development of analysis, synthesis and evaluation capacities: the student has to face up to a problem and solve it.
- Development of transversal skills and competences, such as responsibility, ability to work by themselves and

cooperative work, improvement of oral and written expression, etc.

- Development of a real experience similar to those they can find in a company. There is a client (lecturer's role) and there is a problem that they have to solve; students have to share the tasks, assuming the implementation and delivery timetable.

II. Development of the experience

A fundamental aspect to the development of a PBL experience lies on the planning and preparation stage. Before the beginning of lessons, involved lecturers must discuss the methodology, objectives, establish the work schedule as well as the activities to be developed. They must also establish regular meetings to discuss the project, to coordinate it and to establish, if necessary, corrective actions. The final evaluation will allow the analysis of the factors to be improved for the next academic year. This analysis will let us, year after year, improve the quality of experience.

Some examples of the activities to be carried out by lecturers and/or students may be (they must be established on the initial planning):

- Explanation of the experience to develop.
- Initial explanation of theoretical concepts.
- Allocation of groups, projects and roles.
- Continuous monitoring and evaluation.
- Final Assessment.

These topics will be addressed in depth explanation further on.

III. Explanation of the experience to develop

Lecturers introduce the experience, objectives to goal, methodology followed (PBL), lessons to teach and evaluation system.

IV. Initial explanation of theoretical concepts

The main objective is student acquisition of base knowledge, which is subsequently extended on an autonomous/directed form through the guidance and monitoring. This kind of training may be incorporated at the beginning of the experience or when needed through the implementation process.

V. Allocation of groups, projects and roles

Once the number of enrolled students known and their subjects, the decision of how to create the working groups, (number of components) as well as the characteristics of each project must be carried out.

In the case of working with several subjects, it is possible that students might not be enrolled in all subjects. In this case lecturers must set the work to each student according to the subjects enrolled.

Regarding the creation of the groups, there are several possibilities. The formation of groups can be done by students or lecturers. In general, students give preference to form groups with their friends. However, this may lead to several problems: firstly, a possible lack of integration of

concepts in some groups because of the heterogeneous student enrollment; secondly, a lack of realism with regard to the current professional world. The formation of groups according to the lecturer criteria let experience be as close to real life as possible.

Within every single team different roles must be established, for example, a coordinator and a secretary. The coordinator could be in charge, for example, of moderating team meetings and making the follow-up of the work plan (previously established by the group). Concerning the secretary, he or she should be in charge of preparing the meeting calls and writing the meeting minutes. These roles will be interchanged, so that all group members perform both functions.

VI. Continuous monitoring and evaluation

Throughout the experience period, each team must meet on a weekly basis. The lecturer will carry out the follow-up, guidance and evaluation both as individually and in groups.

We show some of sample activities to be developed:

- a) **Sessions.** Meeting among the students, where they work and perform the different scheduled tasks. The work done by each individual student will be discussed, validate and agreed with the rest of the group. Lecturers will check the development of each group, they will resolve doubts and they will direct the students to find the way to resolve it by them. They will be responsible for guiding the learning of the students. In this environment, they will be observers and guides to get the student's learning.
- b) **Group tutorials and student tutorials.** Lecturer will interview students and check the state of their work. The meetings will be carried out weekly.
- c) **Group exhibitions.** Each team presents its work to the rest of the students. The number of presentations will depend on the experience period and on the number of enrolled students. As an example, we present three possible presentations:
 - Presentation of a detailed analysis of the project to be developed by the team: requirements, planning, resources selected, tasks and people in charge, timing, etc. Students will be in charge of different tasks according to their enrollment and their different subjects.
 - Presentation of a first prototype. Each team will present a first solution to the problem/project set out.
 - Presentation of the final project. Each team will present the solution or the final product done.

The preparation of relevant documentation, carried out by the group, must comply with the planning done. This documentation must summarize both the group work and the project documentation. The lecturer involved will evaluate it.

VII. Final Assessment

The evaluation process will be very important on PBL. Under this methodology, the evaluation must be carried out both on an individual and on a group basis. Both evaluations allow lecturers to establish the final mark of each student. Then, if we work on interdisciplinary projects it will be also usual take into account the work done by each student in each subject. An example of assessment could be:

- a) Project assessment: established by consensus among all lecturers involved. This mark could be for example 50% of the student's final mark. Aspects covered:
 - Final project: 30 %.
 - Presented documents: 15 %.
 - Oral presentations: 5 %.
- b) Individual evaluation: carried out by each lecturer in the concerned subject. It could be for example 50 % of the final grade of a student. The aspects covered could be individual work, effort, and student learning done individually. This mark can be established thanks to the individual follow-up carried out by the lecturer.

The evaluation system should be a motivation source to encourage work as a team for students, because at least half of their marks will depend on the efforts they put altogether in their teams. In turn, the effort and learning at an individual level will be also taken into consideration. So, each student will be able to improve their final grade despite having a not very brilliant team.

Lecturers could decide to take into account an assessment of the group members carried out by each student. For example, lecturers could distribute a survey in which students assess aspects from the rest of the students of his/her team, such as effort, contribution to the project, critical ability, leadership, capacity for dialogue, teamwork, appreciation of the different roles. The survey would complement the mark of each student and let the lecturer have a particular view of the teamwork development more realistic.

EXPERIENCE ON COMPUTER SCIENCE ENGINEERING

Among the different experiences carried out at the Teruel Polytechnic School of Engineering, we present those carried out in Computer Science Engineering. The experiment was fulfilled as a multidisciplinary project that included three courses: 'Strategies and Information Systems', 'Electronic Commerce' and 'User Interfaces'.

The main difference with other PBL experiences lies on the fact that it is carried out on not only one subject but also joining three subjects as if they were only one. It requires a higher coordination of lecturers, the establishment of share timetables to let students work together as well as a great effort from the student side. Then, the job must be carried out in different types of groups because students can be enrolled on one, two or three subjects. Assessment and monitoring is also more difficult, as three teachers must observe the different groups and the individual students to

establish a final mark. However, only one project by group is done.

To carry out student's assessment, lecturers used four weekly hours (work in groups') and six weekly hours (tutorship). The three lecturers meet with all groups, playing several roles. Playing the first one, they show a similar behavior as if they were business's client, asking students about their products. Playing the second one, they behave as observers, seeing how students work together and, playing the third one, they are the student's learning facilitators, making comments and proposing questions that make them think.

Along the experience, lecturers register their observations about students, covering aspects such as integration on the group, developed documentation, attitude on their different roles, their behavior, fluency and knowledge of their presentation and oral/write expression and the quality and marks of the activities carried out both on their own and on the group. Lecturers have a diary of each student, that lets finally assess them. In the same way, students evaluate their team-mates and fill out several surveys along the teaching period, commenting their impressions about the project evolution, the problems they found out and the things they think should be changed.

Projects carried out by the students included aspects such as business management, technical aspects of scheduling, security and development of user interfaces (considering criteria of usability and accessibility). Involved lecturers did belong to two different departments of the University of Zaragoza: Economics and Business Administration Department and Computer Science and Systems Engineering Department.

The number of students was 35 on average, who were enrolled in 1, 2 or 3 subjects. Each group consisted of five members and the projects were based on the creation of an e-business. Some examples of projects carried out were: e-business for rural tourism, e-business for companies' management, virtual newspaper, e-business for a software development company, an on-line insurance company, and so on. Each of these projects included the development of the following aspects:

- Viability plan of the business.
- Analysis and selection of the more appropriate information and communication technologies.
- Usability and accessibility of the Web.
- Establishment of security in accordance with the Data Protection Law.
- Search engine optimization for the on-line business.
- Business strategy and integration, as a source of competitive advantage, with the information systems.

MAIN OUTCOMES AND ADDITIONAL GENERAL CONSIDERATIONS

The continuous assessment of students, the surveys carried out as well as the results obtained let us analyze the experience. We were able to check the usefulness of the

implementation of PBL as a learning tool. Some of the aspects valued were:

- Experience development.
- Development of the generic/specific competences.
- Assessment of the teaching method.

As regards abilities and skills developed by the students, the results obtained coming from the last experience showed that the abilities and skills more developed were: self-learning, knowledge integration, oral and written communication, critical capacity, team work and initiative. Fig. 1 shows the percentages given by students to each one of them. These results were predictable, given the characteristics of PBL. The results obtained let us confirm the usefulness of PBL as active learning method based on both team work and self-learning.

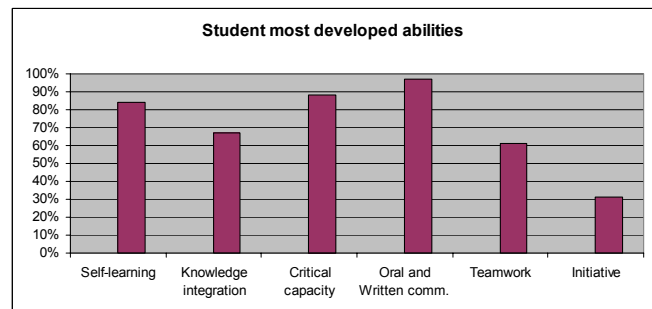


FIGURE 1
STUDENT MOST DEVELOPED ABILITIES

Concerning the usefulness of the experience from the point of view of PBL as a method of learning, students express the need of a greater effort (97%), compared to traditional methods. However, they have also recognized that they have learned more (77%). They also valued its usefulness as an approximation to the real world (90%). In 60% of cases the students recommended this method of learning. They also underlined some difficulties founded. Above all, they claimed lack of time and a greater help from lecturer. Results are reflected on fig. 2.

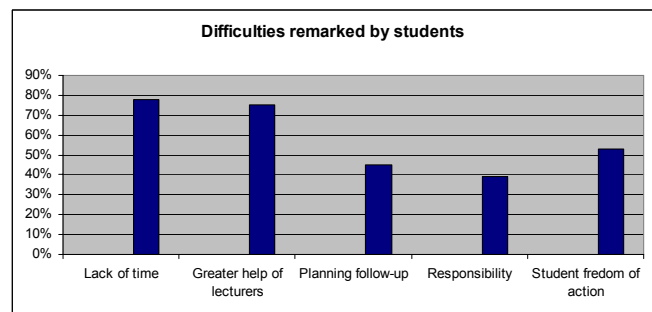


FIGURE 2
DIFFICULTIES REMARKED BY STUDENTS

From the lecturer point of view, we can highlight especially the usefulness of this experience as regards the integration of knowledge by students, the positive value of teamwork and the good communication among its members. This fact implies that the determination to form working

groups by lecturers does not affect the subsequent relationship between the group members.

As far as lecturer workload is concerned, we can say that it is similar or slightly superior to the one done with traditional teaching methods. The workload will be higher especially when the interdisciplinary experience is designed.

Subsequently, along the development of the experience, the workload was similar to that supported by traditional methods: lectures were replaced by group sessions, interviews, presentations, tutorships, tutorials, etc. The number of students will be other factor to take into account.

Another aspect to consider will be the problems derived from the curricula and courses. It will be necessary to chose subjects being complementary and susceptible to carrying out joint projects. In addition, the workload increase noted by students (more than the one due to traditional methods) must be controlled. The project should not interfere in the development of other subjects not included in the experience. The results showed that, on average, about 85% of students past the project in the first examination. That means they passed three subjects altogether with an integrated project.

CONCLUSIONS

The use of active methodologies based on student learning facilitates the development of competences and skills. One of the main methodologies for continuous learning is the Problem-Based Learning (PBL). In this methodology, students play an active role in their own learning. It allows students to get a better understanding of difficult concepts and let them retain the knowledge acquired for a long period of time. In addition, students are able to develop the professional qualities required in the business world, such as critical capacity, communication ability, planning ability, autonomy, capacity of work in group, etc. In this work, and through the implementation of different experiences in the field of engineering, we have presented the main aspects to take into account if similar experiences are going to be carried out. Finally, we have presented and analyzed the results obtained in an experience carried out within the framework of a Computer Engineering degree.

REFERENCES

- [1] Joint declaration of the European Ministers of Education Convened in Bologna on the 19th of June 1999, European Ministers of Education. [Online]. 2004. Available: <http://www-en.us.es/us/temasuniv/espacio-euro>.
- [2] Cortes Generales, 'Ley Orgánica de Universidades', Boletín Oficial de las Cortes Generales, Vol 45-13, 26th December 2001, pp. 463 – 495 ('Organic Law of Universities', Official publication of the Spanish Congress).

- [3] Tuning Project. Website University of Deusto [Online]. Available <http://tuning.unideusto.org/tuningeu/>.
- [4] ANECA (Spanish National Agency for Quality Assessment and Accreditation). Website: <http://www.aneca.es/activin/docs/>.
- [5] La Declaración de Bolonia y su repercusión en la estructura de las titulaciones en España. 8 de julio de 2002. Conferencia de Rectores de las Universidades Españolas.
- [6] Sánchez, F. and Sancho, M. 2003. Repercusiones el futuro espacio europeo de educación superior sobre las titulaciones universitarias de Informática en España. IX Jornadas de Enseñanza Universitaria de la Informática.
- [7] Carmaña, C., Ballester E., Coll C., García E. 2003. Mitos y realidades de la innovación educativa. XI Congreso Universitario de Innovación Educativa en las Enseñanzas Técnicas, Vilanova i la Geltrú.
- [8] Joint declaration of the European Ministers of Education Convened in Bologna on the 19th of June 1999. European Ministers of Education. [Online]. Available: <http://www-en.us.es/us/temasuniv/espacio-euro>. 2004.
- [9] Oliver, J. 2003. El futuro de la formación de los profesionales informáticos. IX Jornadas de Enseñanza Universitaria de la Informática. Cadiz.
- [10] ABET (Accreditation Board for Engineering and Technology), Criteria for Accrediting Engineering Programs. Website: <http://www.abet.org/>.
- [11] Woods D.R., Felder, R.M., Rugarcia, A. and Stice, J.E. 2000. The future of engineering education. Developing Critical Skills. Chem. Engr. Education, 34(2), 108-117 (2000).
- [12] Alcober, J., Ruiz S. and Valero, M. 2003. Evaluación de la implantación del aprendizaje basado en proyectos en la EPSC (2001-2003). XI Congreso Universitario de Innovación Educativa en las Enseñanzas Técnicas, Vilanova i la Geltrú.
- [13] Rondon, A. Metodología del Caso y Aprendizaje Basado en Problemas. Institut de Ciències d l'Educacio, Universitat Autònoma de Barcelona
- [14] http://www.pbli.org/pbl/generic_pbl.htm: Accessed: 21 March 2009.
- [15] Dirección de Investigación y Desarrollo Educativo, Vicerrectoría Académica, Instituto Tecnológico y de Estudios Superiores de Monterrey, El Aprendizaje Basado en Problemas como técnica didáctica

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