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Acquisition of transversal skills through PBL: a study of the perceptions of the students and teachers in materials science courses in engineering

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Abstract
The main goal of this work is describing the experience in using Project Based Learning (PBL) methodology in Materials Science courses in several Engineering degrees. The courses were taught simultaneously in four different Spanish universities. In addition, the impact of this proposal on the acquisition of transversal skills through the perceptions of students and teachers is assessed. In order to do so, voices of over 54 students and 5 lecturers involved in the work have been gathered and studied descriptively. Discussion groups and self-reports have been collected and subsequently analysed. The analysis of the data collected by these two instruments has been coded and categorized into general dimensions. The results show how,

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through the PBL, self-learning is encouraged and the development of transversal skills such as teamwork are enhanced. Meanwhile, the lecturers consider PBL an appropriate methodology for Materials Science courses; however its implementation requires a higher work load. The faculty acknowledged PBL as a very interesting tool to work and evaluate transversal competences. Hence, the PBL methodology stands as one of the most effective methods that meet the demands of the 21st century and enables students to acquire not only content based knowledge, but also other abilities.

Keywords
Active learning methods; teaching methodologies; European higher education area

1. Introduction

Competence can be defined as «the ability to tackle a range of similar situations in an efficient manner. This is done by combining consciously, quickly and creatively a number of cognitive skills; knowledge, capacities, micro-competences, information management, attitudes, ways of perception and evaluation» (Perrenoud, 2001:9).

For Engineering degrees, in addition to theoretical and practical skills acquired during the degree, a number of other skills should be grasped, including social skills and independent working. Such a comprehensive education will make it possible to develop successfully a professional career. These abilities are named cross curricular competences because they do not belong to one particular subject or even a degree, but make the performance and success to increase manifolds. Other examples of such cross curricular competences are time management, efficient communication, public speaking, independent information searching skills, leadership and problem solving. As a consequence, the latest changes in the higher education curriculum promoted by the European Higher Education Area (EHEA) march in this direction (Carreras, 2008). Nevertheless, these changes are still hotly debated because of the difficulties of integrating them.

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PBL learning has been demonstrated to be among the most effective teaching tools and assessment methods towards this new goal. In addition, PBL also deals with a number of other issues introduced by the new education system. For example, it helps distributing the time devoted by students for the different modules, both in the classroom and outside the classroom, in accordance to the credit system ECTS. In addition PBL contributes to the developing of cross curricular skills during the degree (Carreras, 2008). The evaluation of such cross curricular skills in traditional teaching methods is a difficult task. However, PBL allows one to incorporate easily the evaluation of such cross curricular skills (Valero, 2011; Valero 2007).

The PBL is a model of learning in which students raise, implement and evaluate projects that have an application in the real world. This method uses problems as a starting point for the acquisition and integration of new knowledge (Barrows, 1986). As other methodologies, it requires a series of well-structured and planned steps set by the teacher.

Moust, Bouhuijs and Schmidt (2007) and Schmidt (1983) proposed seven steps to implement the resolution of the project:

1. Clarification of concepts and terms that appear in the proposal project from the dialogue between group members.

2. First tentative definition of the problem. After steps 3 and 4 this step can be repeated if considered necessary.

3. Analysis of the problem from the contributions of all group members through brainstorming.

4. Development of a systematic summary with several explanations to the analysis of the previous step. Once generated the greatest number of ideas about the problem, the group tries to systematize and organize them, highlighting the possible associations among them.

5. Set up of learning objectives and common decision on aspects of the problem, which are to be investigated and understood.

http://dx.doi.org/10.4995/muse.2014.3896
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6. Search for more information, individually.

7. Synthesis of collected information and writing a report on the acquired knowledge.

These phases point out the many cognitive processes and competencies required to the students. Given the generic nature of PBL activities, the students improve a wide range of cross curricular skills such as problem solving, decision making, teamwork and communication (de Miguel, 2005). Thus, knowledge is gained while they learn to learn in a progressively independent way as well as they learn to apply that knowledge in solving various problems similar to those they face in the performance of different facets of this work: working in teams under supervision, being progressively autonomous, identifying learning goals, managing time effectively, identifying which aspects of the problem can be ignored or need to explore more deeply and investigating on their own, thus directing their own learning. Through this process, they benefit from the participating peers, which provide the necessary contrast to their inquiries and ways of understanding what they are studying (Vizcarro and Juárez, 2009).

One of the strengths that characterize the PBL is its application to different educational levels as well as its versatility to be able to deal with various areas of knowledge. The literature review offers examples of these benefits. Reeves and Laffey (1999) used PBL in an Introduction to Engineering lecture and found an increase in the students' problem-solving skills. However, its implementation in the materials science knowledge area is not very common, being that one of the most traditional engineering subjects and where the introduction of non-traditional teaching methods such as PBL seems to be more difficult. In this sense, Jonassen and Kanna (Jonassen and Khanna, 2011) have analysed the feasibility of introducing a similar methodology (PBL) in a subject in the field of Materials Science for Mechanical Engineers at the University of Missouri and have found that this methodology is very difficult to implement unless this introduction is carried out in curricular way. Thus, their findings show that the introduction of this methodology in only one subject (for this type of degrees) requires great effort from both parties involved: teachers and students, whereas if the methodology is implemented at the level

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EISSN: 2341-2593

of curriculum for the whole degree, it is much more effective than the traditional learning methodologies.

The main objectives of this work are two. Firstly, to describe a PBL methodology developed simultaneously in Materials Science course of four Spanish universities. Secondly, to assessing how the new PBL methodology helps the students to develop cross curricular skills. This will be done by analysing the experiences of both students and lecturers.

2. Proposed methodology: integration of different teaching methods

2.1. Didactic methods

The experience described here is part of IdM@ti (acronym in Spanish for Network of Educational Innovation in Materials Science). IdM@ti is formed by lecturers from seven Spanish universities. Within this network, it was decided to implement the PBL simultaneously on their respective courses, with the aim of analysing if it was possible to apply it in subjects in this field, regardless the specific degree in which the course is given or any other particular situation of the university. The participating universities were University of the Basque Country (hereinafter UPV/EHU), Jaume I University (hereinafter UJI), Universitat de Barcelona (hereinafter UB) and University of Malaga (hereinafter UMA).

The activity was developed with students from the universities enrolled in different degrees and studying courses related to Materials Science. All degrees were in the field of engineering. As a common element to all projects, the methodology is structured in three sections defined in the documentation provided to the students:

-The project and its objectives.

-A closed proposal with minimal requirements within and outside the classroom.

http://dx.doi.org/10.4995/muse.2014.3896
EISSN: 2341-2593

-The exact details of the evaluation methodology.

With such common criteria, each participating university adapted the methodology to their needs and abilities.

The main focus of each PBL project was to study the design of a commercial product. Once the current design was thoroughly analysed from a Materials Science view point, the product was redesigned, with the aim of improving a type of properties. The choice of the product to be studied was based on the following criteria: to be affordable for the development of the activity; to involve a wide range of teaching materials of interest; and to be disassembled easily so that each component can be analysed separately.

The idea of the PBL is to reproduce as closely as possible the conditions under which engineers work in companies. The following generic skills have been identified to be needed when working for a company:

1. Own work management
2. Summarising and managing information
3. Decision making
4. Problem solving
5. Information searching skills
6. Technical communication skills (oral and written)
7. Critical awareness when reasoning
8. Adaptation to new situations
9. Creativity
10. Entrepreneurial skills
11. Awareness about quality
12. Project design and management
13. Team working
14. Negotiating work load
15. Discussing, listening and finding agreements

http://dx.doi.org/10.4995/muse.2014.3896
EISSN: 2341-2593

16. Team working towards enhanced learning

PBL was designed in a way such that these skills are practised. Thus PBL allows us to expose the engineering student to conditions as similar as possible to conditions in engineering jobs.

Cross curricular skills were evaluated regularly through rubrics. A number of rubrics were designed to assess tasks such as minutes of meetings, participation in wikis, ICT use, content and presentation videos, reports, etc.

2.2 Study description

2.2.1 Methodology

This works is based on a descriptive method. The methods is based on understanding the perceptions of lecturers and students about how cross curricular skills are trained with PBL activities (Hernández, Fernández y Baptista, 2001). Perceptions were studied by surveys based both on multiple choice questions and on open questions.

2.2.2. Participants

The target population of this study was the students and lecturers of 4 different universities. Students who were involved in PBL learning were asked to answer a survey. The final sample was 54 students and 5 lecturers from the different universities taking part in the study.

2.2.3. Tools for gathering information

Qualitative information was collected through a survey with open questions about how cross curricular objectives were met with PBL. Students and lecturers were asked to think about how the project has influenced them.

This qualitative information was complemented with another survey based on multiple choice questions. Only students were asked to answer this second survey. 17 questions were asked about in this second survey. Answers were given following a Liker type scale

http://dx.doi.org/10.4995/muse.2014.3896
EISSN: 2341-2593

(1. Strongly disagree; 2. Disagree; 3. Uncertain; 4. Agree; 5. Strongly agree). The survey included a number of questions about how the project helped them in acquiring cross curricular skills.

2.2.4. Analysing the results

The survey was created through Google Drive platform that allowed delivery to all participants, students and lecturers. Statistical treatment of data was done with the help of software SPSS (IBM Corp. Released 2010. IBM SPSS Statistics for Windows, Version 19.0. Armonk, NY: IBM Corp.). The study was based on frequency analysis of the multiple choice questions. Open questions were evaluated by examining their content.

3. Discussion of the proposal and results

3.1. Qualitative analysis

First, the surveys answered by lecturers are summarised and discussed and then the surveys answered by the students are shown.

Lecturers believe that PBL helped developing skills such as independent working, information searching techniques, presenting results, team working, leadership, entrepreneurial skills and creativity.

A gradual increase in *independent working* for problem solving and decision making has been observed through the course. Initially, student groups required often supervising and assistance. The authors believe this initial behaviour was due to the novel methodology employed in the course, where no previous outline of tasks is given. However, it was observed that as the course progressed, the meetings between the student groups and the lecturer were used more and more as an opportunity to share information and verify that work was done is the right direction.

Students developed *information searching techniques* by looking up and exploring different sources, such as patents, scientific papers, text books, internet website, etc. The

http://dx.doi.org/10.4995/muse.2014.3896
EISSN: 2341-2593

results were presented periodically, both through oral presentations and written essays. This helped developing communicative skills that are key once the students graduate. *Team work* skills were also trained, since the vast majority of activities were developed in groups. A range of experiences were found in the different universities. Some lecturers believe that team working has been smooth and minor problems that appeared were easily settled as time went by. However, when the duration of the project was short, it was often found that problems were not settled. These experiences often happened when students did not seek for help from the lecturer when the problem arises. In general, PBL help student to establish deadlines with team mates, negotiate working load, share knowledge and communicate via tools such as email, Dropbox and WhatsApp.

One member of the team normally took the *leader* position. This involved distributing tasks, team coordination and cheering up the group. When the leader was acknowledged by the other members, conflict resolution tended to be easier and faster.

In one of the PBL experiences, it was found that entrepreneurial skills and creativity were also strengthen, since the student has to combine a wide range of knowledge learned during the degree to solve problems similar to those met in real working life.

Compared to traditional teaching methodologies based on exams and lab essays, cross curricular skills are promoted much more in PBL based methodologies. In addition, standard evaluation tests do not allow assessing such skills. Cross curricular skills can be easily evaluated through rubrics. A number of rubrics were designed to assess oral presentations, essay writing and team working.

The results of the student survey show clearly that students believe that self-learning is the skill mostly fostered through PBL activities. The fact that they had to "sort out they own problems" made them responsible of their own learning. It was also very useful to understand the practical use of many subjects covered in the Materials Science course. It can also be observed that students believe PBL has improved them in dealing with team working. They also have concerns related to the different levels of commitment by the team members. Nevertheless, these differences are overall rated as positive by the

http://dx.doi.org/10.4995/muse.2014.3896
EISSN: 2341-2593

students. For the sake of fairness, they believe peer to peer evaluation would be very advantageous. This would allow them to distinguish between students with different levels of involvement on the project. Students believed these situations were partially the lecturer's fault and suggest there should exist a procedure to avoid such inequalities in terms of involvement. Students believe that experience based learning, unlike rote learning, is more long-lasting: "Other methods might be able to cover larger course contents, but will soon forget about them". Students also believe that they have faced a nearly real working experience which will help them being more efficient in the future when they get a job. In summary, they believe they have learned a greater deal of useful contents and skills somehow related to Materials Science because they have applied them to a practical situation, they had the possibility to link ideas leant in different course and they spent a long time working on the course.

3.2. Quantitative analysis

Quantitative analysis was done based on the multiple choice survey. Students were asked to assess how the project has helped them to acquire each skill. The results are summarised in Tables 1 to 5 and Figure 1.

Table 1. Survey results for cross curricular skills (I)

Skill	1. Own work management		2. Summarising and managing information		3. Decision making		4. Problem solving	
Answers	Freq.	%	Freq.	%	Freq.	%	Freq.	%
1.Strongly disagree	0	0	0	0	0	0	0	0
2. Disagree	5	9,3	3	5,6	0	0	1	1,9
3. Uncertain	18	33,3	15	27,8	8	14,8	9	16,7
4. Agree	20	37	26	48,1	26	48,1	30	55,6
5. Strongly agree	11	20,4	10	18,5	20	37	14	25,9
Total	54	100	54	100	54	100	54	100

Table 1 shows that 57.8% of students agrees or strongly agrees with respect own work management. 33.3% of students believe they have learned something and 9.3% have learned little. 48.1% of students believe the project has helped them much in learning how to summarise and manage the information, 18.5% of the sample thinks the project

http://dx.doi.org/10.4995/muse.2014.3896
EISSN: 2341-2593

has helped them very much, 27.8% thinks the project has helped them somewhat and only 5.6% thinks the project has helped them little. Answers related to decision making are in the very much, much, somewhat and little ranges, with values 37%, 48.1% and 14.8% respectively. 25.9% of the sample believes PBL has helped them very much to learn skills related to problem solving, 55.6% believes it has helped them much, 16.7% believes it has helped them something and one person believes it has helped him/her little.

Table 2. Survey results for cross curricular skills (II)

Skill	5. Information searching skills		6. Technical communication skills (oral and written)		7. Critical awareness when reasoning		8. Adaptation to new situations	
Answers	Freq.	%	Freq.	%	Freq.	%	Freq.	%
1.Strongly disagree	0	0	0	0	0	0	0	0
2. Disagree	2	3,7	4	7,4	0	0	1	1,9
3. Uncertain	12	22,2	13	24,1	12	22,2	14	25,9
4. Agree	29	53,7	23	42,6	31	57,4	24	44,4
5. Strongly agree	11	20,4	14	25,9	11	20,4	15	27,8
Total	54	100	54	100	54	100	54	100

Table 2 shows that 20.4% of the students believe the methodology allowed them to improve very much their searching skills, 53.7% much, 22.2% somewhat and only 3.7% believes it has helped them little. As regards the sixth skill, 25.9% believes they have trained and improved very much technical communication skills, 42.6% much, 24.1% somewhat and 7.4% little. Additionally, 20.4% of the students points out that PBL has helped them very much to be critically aware when reasoning, 57% much and 22.2% somewhat. Regarding the following skill, 27.8% believes that the methodology has helped them very much in getting adapted to new situations, 44.4% much, 25.9% somewhat and only one person little.

Table 3. Survey results for cross curricular skills (III)

Skill	9. Creativity		10. Entrepreneurial skills		11. Awareness about quality		12. Project design and management	
Answers	Freq.	%	Freq.	%	Freq.	%	Freq.	%
1.Strongly disagree	0	0	0	0	1	1,9	1	1,9
2. Disagree	1	1,9	1	1,9	0	0	0	0
3. Uncertain	12	22,2	7	13	7	13	11	20,4
4. Agree	26	48,1	32	59,3	31	57,4	24	44,4
5. Strongly agree	15	27,8	14	25,9	15	27,8	18	33,3

http://dx.doi.org/10.4995/muse.2014.3896
EISSN: 2341-2593

Total	54	100	54	100	54	100	54	100

Table 4. Survey results for cross curricular skills (IV)

Skill	13. Responsibility towards learning	
Answers	Freq.	%
1.Strongly disagree	0	0
2. Disagree	1	1,9
3. Uncertain	8	14,8
4. Agree	30	55,6
5. Strongly agree	15	27,8
Total	54	100

In the question related to the creativity, 27.8% believes they have very much seized this skill, 48.1% much, 22.2% somewhat and 1.9% little. It can also be seen that 25.9% believes they have worked very much entrepreneurial abilities through PBL, 59.3% much, 13% somewhat and 1.9% little. When the students were asked about how PBL has helped them to be aware about the quality, 27.8% thinks it has helped them very much, 57.4% much, 13% something and only one student believes it has helped him/her little. Table 3 also shows that 33.3% of students believes PBL has helped them very much to improve their project design and management skills, 44.4% much, 20.4% somewhat and 1.9% little. It can also be seen that 27.8% of students see PBL as a very good tool to be responsible of their own learning, 55.6% thinks it is good, 14.8% thinks it is moderately useful and 1.9% thinks is not very useful.

The students perception of skills related to team working skills are summarised in Table 5.

Table 5. Survey results for team working related skills

Skill	14. Team working		15. Negotiating work load		16. Discussing, listening and finding agreements		17. Team working towards enhanced learning	
Answers	Freq.	%	Freq.	%	Freq.	%	Freq.	%
1.Strongly disagree	1	1,9	0	0	1	1,9	1	1,9
2. Disagree	2	3,7	3	5,6	2	3,7	2	3,7
3. Uncertain	11	20,4	10	18,5	10	18,5	13	24,1
4. Agree	24	44,4	29	53,7	32	59,3	24	44,4
5. Strongly agree	16	29,6	12	22,2	9	16,7	14	25,9
Total	54	100	54	100	54	100	54	100

http://dx.doi.org/10.4995/muse.2014.3896
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Table 5 shows that 29.6% of the samples believes that PBL has improved very much their abilities towards team working, 44.4% much, 20.4% somewhat and 5.6% of the students believes the methodology is little or not useful at all to improve team working skills. 22.2% thinks they have learnt very much to negotiate working load with their peers, 53.7% much, 18.5% little and 5.6% little. Additionally, 16.7% of the students believe the project has helped them very much is discussing, listening and finding agreements, 59.3% much, 18.5% somewhat, 3.7% little and 1.9% nothing at all. Finally, 25.9% of the students worked in teams very much towards an enhanced learning, 44.4% much, 24.1% somewhat, 3.7% little and 1.9% nothing at all.

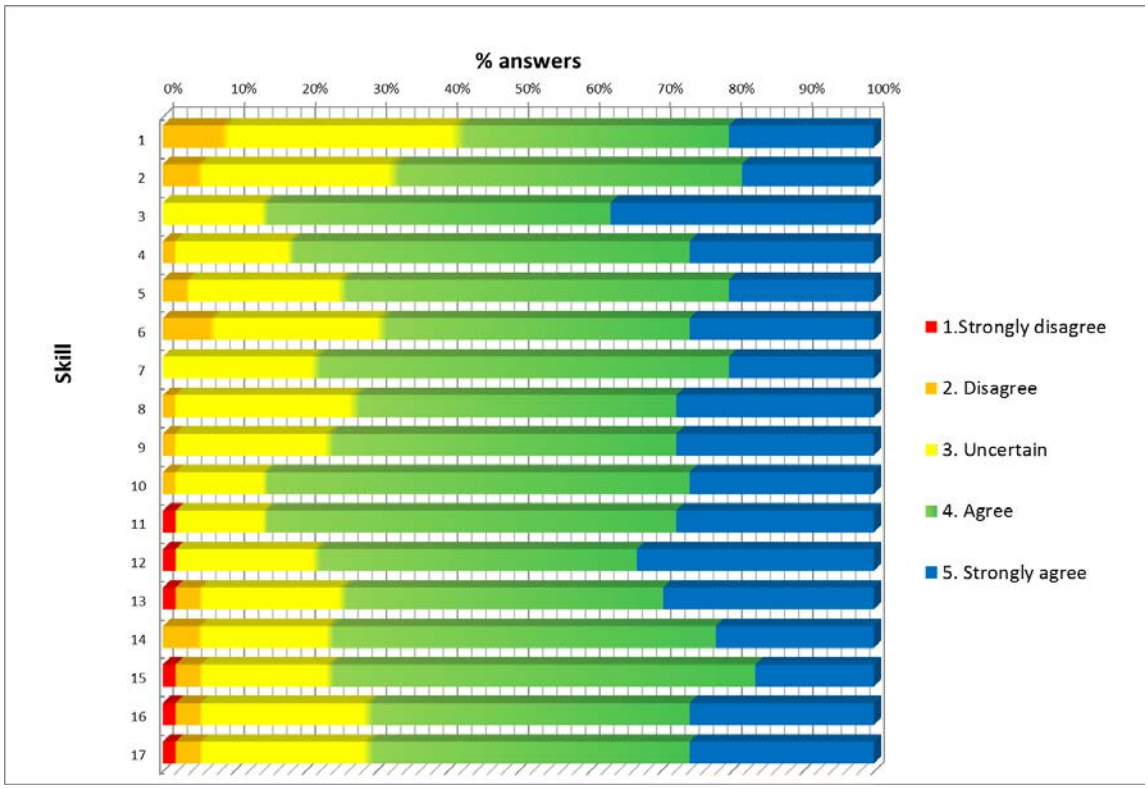

Figure I. Survey results

http://dx.doi.org/10.4995/muse.2014.3896
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4. Discussion

The results clearly show that cross curricular skills were trained and improved through PBL methodology. Very good agreement between lecturers and students was observed in self learning and team working skills.

Table 4 shows that 83.4% of students have been responsible for their own learning, in agreement with previous works where this skill was also evaluated, Kay et. al (2000), Chin &Chia (2010) o Sungur, Tekkaya & Geban (2010). This suggests that students are quite involved in building up their knowledge based on previous experiences and learning. Such knowledge can be used and applied in a wide range of situations. According to the survey, other skills closely related to self-learning also achieved good scoring. Skills such as summarising and managing information, information searching skills and decision making scored more than 60%, 75% and more than 80% respectively.

This latter point is key in the current society with increasing complexity and an ever higher number of challenges and demands. One of the factors responsible for the increasing complexity of the society is the development of new ICTs along with new systems of communication and information sources. This fact makes necessary a change in the role of the teachers with respect to the traditional one (Marcelo, 2001).

Thus, the job and main tasks of the lecturers are renovated and they become helpers towards the learning process of the student. The use of PBL requires a change in the main functions of the lecturers but also a change on evaluation methods. Traditional pedagogic methodologies cannot be used to evaluate cross curricular skills and a new evaluation system is required. This new system must be more dynamic and much included the knowledge, the know-how and how to behave (Alsina, 2011). The ideal method for evaluation requires the student to assimilate knowledge, skills and attitudes. Such method leads to facing reasonably complex tasks, generally involving a range of different subjects (Monereo, 2009:92). Thus, PBL is a methodology that promotes an educational evaluation aiming at improving the learning process. Such evaluation can be done through learning rubrics. These tools, together with other tools suggested by the students,

http://dx.doi.org/10.4995/muse.2014.3896
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such as self-assessment and peer assessment, can help the lecturers to improve this skill-based approach.

Regarding team working skills, surveys reveal that 75% of students understand that PBL has helped them to strengthen this skill and other related skills such as negotiating, discussing, listening and finding agreements with their peers. Nevertheless, students have experienced a number of difficulties often appearing when team working. Most of these problems can be solved with self-responsibility. Each team member must take responsibility for the tasks and goals that were assigned to him/her. Committing oneself for different tasks is the best way to produce good group results. This degree to which members of the group are mutually dependent on each other, named interdependence, increases the motivation and thus the performance, both from the group as a whole and of each team member. Prieto (2007) points out that self-responsibility means that each member should contribute somehow towards the learning process and the success of the group. In addition, self-responsibility also means that each member should be able to demonstrate his/her skill to his/her peers.

Consequently, it is very advisable to spend some time at the beginning of the project to raise awareness about team working and make commitment to complete different jobs defined by the group. Such approach can be enhanced by involving all team members in leading the group. This can be done by exchange periodically the functions within the group.

5. Conclusions

The current work explains in detail a number of advantages and disadvantages of PBL. The authors believe the experiences herein described can be very useful to other lecturers that are considering introducing PBL in their courses and also to lecturers that have already put PBL into practice.

Overall good agreement was observed on how students and lecturers perceive PBL activities. Most activities are rated as very positive, both by the students and the lecturers.

We have demonstrated that PBL is a very powerful tool to improve and evaluate cross curricular skills in Materials Science courses of Engineering degrees.

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