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Using the Project Based Learning (PBL) Methodology to Assure a Holistic and Experiential Learning on a Master's Degree on Technology for Human Development and Cooperation*

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This paper presents an innovative experience applying PBL methodology simultaneously to eight different subjects in a Master's Degree on Technology for Human Development of the Technical University of Madrid run by the Innovation and Technology for Development Centre (itdUPM). Students are encouraged to work on a real project considering multidisciplinary aspects but always working on the same project, in real and developing context, demanding intense and critical coordination between professors.

During the experience, the following competencies are strengthened: communication, team working and ability to analyse different socio-technical alternative based on economic, social and environmental aspects. The paper presents methodology, assessments, results, difficulties found and new challenges, as an example for potential replicability in other universities.

Keywords: project based learning; technology for human development; holistic and experiential learning in different areas of engineering

1. Introduction

The work presented in this paper introduces the efforts made within the Master's Degree on Technology for Human Development (MTHDC) of the Technical University of Madrid (UPM) to offer a continuous learning process for students through the Project Based Learning (PBL) methodology, strengthening the knowledge and capabilities acquired by students during the Master's Degree.

PBL method consists of a collaborative teaching system [1]. It focuses on a more active student participation, involving them in active search to solve a real problem in a real context. It encourages and motivates students learning technology subjects, taking an active role [2–4]. Gordon [5] was the first author who distinguished between academic challenges, situation challenges and real-life challenges.

As engineering is an applied discipline where students learn by doing, PBL has proved to be a highly versatile tool to strengthen knowledge and behavioural skills [6]. Moreover, previous research shows that students are more motivated and work much harder with a PBL model than with traditional teaching methods [7]. Most of the learning process takes place in teams that must work cooperatively to achieve the success. For this reason, competencies like teamwork and effective communication are improved. In addition, PBL is generally applied to open-ended problems and requires the ability to process and discuss ideas and learn autonomously [8].

Worldwide, PBL has been successfully applied to different contexts and in many universities (including interesting initiatives from UPM teachers) [e.g. 1, 7, 9, 10]. Furthermore, some authors use PBL to strengthen some specific competencies [11, 12] while others presented analysis of process, difficulties and recommendations of its application [13, 14]. All the experiences found in the literature review have been applied to a single subject in different contexts.

Regarding the topic of the Master's Degree, the role of technology for human development is well established and has gained recognition since the publication of the Human Development Report of 2001, *"Making new technologies work for human development"* by the United Nations Development Program [15]. During the last decades technology has played a key role in the development agenda. In the new international Agenda, as reflected in the Sustainable Development Goals [16], this role will be even more determined in supplying social and environmental sustainable energy and productive

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systems, contributing at the same time to human development, especially in developing countries [17].

Both in the international and national context, Master's Degrees about human development and cooperation are quite common. In Spain, most of them cover the topic from a general perspective. Apart from the MTHDC, none of them enclose the technology for human development and cooperation with the exception of one itinerary on the Master's Degree in Sustainability Science and Technology of the Technical University of Catalunya [18], which was developed based on the UPM experience. In the international context, the variety is bigger but even in the most recognised research centres and universities working on human development and cooperation there is not any approach as holistic as the MTHDC. In this case, Master's Degrees vary from the general perspective [19, 20] to very specific topics as energy [21], water [22], development economics [23] or innovation [24].

The first edition of the MTHDC was held in the academic year 2010/11. The Master's Degree programme has gained recognition in its knowledge area during the following years becoming one of the most important in the area of development in Spain. The MTHDC aims to offer a comprehensive education on engineering applied to human and sustainable development with the following general objective:

> *''To train professionals in the identification and implementation of mixed approaches and solutions, both technical and social, to promote Sustainable Human Development and develop international cooperation projects''.*

As a specific objective, these professionals must achieve knowledge on appropriate techniques under development contexts in different areas of engineering, with a holistic view.

To achieve these objectives, the Master's Degree has 90 European Credit Transfer System (ECTS) and is organised in three semesters (Table A.4), (1) focused on general concepts about human and sustainable development, (2) focused on the relationship of the different engineering areas with human and sustainable development and how to adapt technical solutions to developing countries and (3) practically oriented facilitating students to make a professional internship working on a real project and the Master's Degree Thesis.

During the first four editions, students specialized in the second semester in different areas of engineering: appropriate technologies for the provision of basic services, ICT, rural development and agroforestry and territorial and urban development.

In the fifth edition (academic year 2014/15), the second semester approach moved from specialisation in one specific area to a unique comprehensive itinerary. In order to assure a holistic and experiential learning, the PBL methodology was introduced in every subject, apart from one subject from the first semester. A general objective was proposed as guiding thread for the whole process and in each subject specific objectives were proposed to accomplish it *(''To develop a comprehensive programme to improve living conditions of the inhabitants of the Alagoan Semiarid Region (Brazil), including coexistence, widening the access to basic services''*). The proposed project was located in the Alagoan semiarid, in Brazil. The application of the methodology was supported by a local NGO, ''Instituto Brasileiro de Desenvolvimento e Sustentabilidade (IABS)''.

2. The project based learning methodology in the MTHDC

2.1 The PBL

In the MTHDC, the PBL methodology is applied during part of the first semester (1 subject) and the

Fig. 1. Caatinga degraded area in the Alagoan Semiarid Region (Brazil).

Fig. 2. Typical house with a rainwater harvesting tank implemented by IABS in the Alagoan Semiarid Region (Brazil).

second semester (7 subjects) (36 ECTS), working more than 6 months. The general objective of the PBL is:

> *''To develop a comprehensive programme to improve living conditions of the inhabitants of the Alagoan Semiarid Region (Brazil), including coexistence, widening the access to basic services''.*

The PBL was conceived to be based on the local reality as much as possible. To achieve that, the Brazilian NGO IABS supported all the process, from the design of the project to the evaluation of final projects, throughout the development of the PBL.

Apart from the typical objectives considered under a PBL methodology and the specific objectives included in the Master's Degree programme, the methodology is aiming to achieve the following objectives for the students:

- To strengthen the ability to function on multidisciplinary and international teams as needed for good performance when working in developing countries.
- To understand how problems are interrelated on the provision of basic services in developing countries.
- To be able to analyse problems and technical solutions with a human and sustainable development perspective.
- To work on a real problem and to look for applicable solutions based on real data and with feedback from one organisation based on the area of concern.

In addition, some objectives for the university are also aimed for. It is expected to strengthen the training offer of the MTHDC with an innovative methodology. Also, it is expected to strengthen the capabilities of lecturers and researchers from different engineering areas and faculties to work together, both for teaching and research, with an interdisciplinary approach and to reinforce their relationships.

Regarding the participation of IABS, the PBL aims to fortify the strategic and long-term relationship between both organisations. IABS and itdUPM have been working together since 2013 in research projects and training activities. itdUPM has conducted for IABS the assessment of the scholar water tanks project implemented in the Alagoan Semiarid Region [25, 26] and give strategic advice in several activities like *''Premio Mandacarú''* or *''Centro Xingó''*. In the MTHDC, IABS has participated giving lectures and every year several students make their professional internship within their projects and its staff acts as professional tutors.

In the 2014/15 edition, 12 students took part on the MTDHC. During all the PBL subjects (Table 1) students worked in groups (the same during the full course), 3 groups made from 4 students each. Groups were formed to ensure interdisciplinary and gender balance.

Table 1. Subjects participating on the PBL

Subject	ECTS
Aid Cycle Methodologies	6
Territorial Development	5
Geographic Information Systems (GIS)	5
Water and Human Development	4
Energy and Human Development	4
Agro-forestry Systems, Agriculture and Human Development	4
Constructive Technologies and Basic Habitability	4
ICT for Human Development	4
Total	36

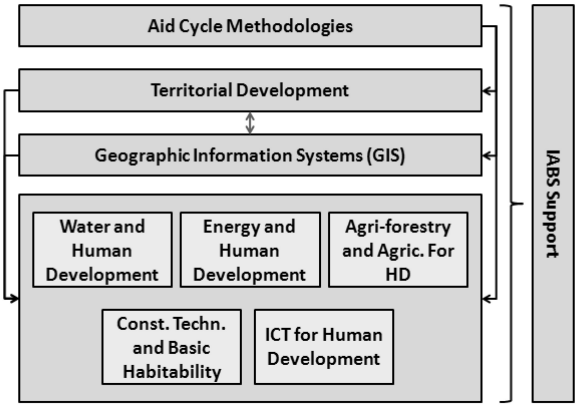


Fig. 3. Structure of subjects participating on the PBL.

Subjects were structured (Fig.2) in three ''general subjects'' (Aid Cycle Methodologies, Territorial Development and GIS) that provided the basis for the five ''technical subjects'' (Water, Energy, Agro-Forestry and Agriculture, Construction Technologies and Basic Habitability and ICT), with transversal support of IABS during the whole process.

Each subject has a responsible professor that has actively participated in the development of the PBL. To accomplish the general objective of the PBL, a specific objective is developed in each subject. Also, different intermediate and final deliverables and oral presentations are done by student teams in order to achieve the specific objectives. Professors of each subject coordinated amongst themselves to establish the date for the different milestones, trying to distribute the work load equitably during the 6 months.

In addition, IABS has supported all the processes in different aspects. During the design of the PBL, they advised lecturers involved in the PBL ensuring that general and specific objectives on each subject were related with real needs from the local population. Also, it gathered and provided information

and data from the area of work. During the process, it provided advice, both on the general process and on each subject, to ensure that deliverables and solutions applied by students were consistent with the local reality.

This process, applied for first time in the academic year 2014/15, supposed a big change in the MTHDC learning paradigm. In addition, some innovation aspects in how PBL methodology is normally apply were also introduced. The main innovation aspects were:

- The change of the learning paradigm of the Master's Degree, from a lecturer based learning where students apply their knowledge in a final work for each subject, to one where students have to find data, information and learn by themselves and the lecturer acts as supporter and adviser.
- Normally a PBL is applied to one individual subject. In this case, the same PBL is applied in 8 different subjects maintaining the same logical structure in all of them and relating the subjects in a proper way to accomplish the overall objective.
- PBL is based on real problems and students must try to obtain real results considering multidisciplinary aspects. In this case, and especially in a developing environment, a NGO with wide experience on the area of work accompanied the process. This assured the quality of the knowledge acquired by students and the quality of results.
- A comprehensive knowledge on how interrelated problems on the provision of basic services in developing countries are is achieved. Previously to the introduction of this methodology, technical subjects were taught separately and relationships between them where not so clear for students.
- Competencies assessment during every course.

Fig. 4. Example of students' final presentations.

2.2 Evaluation criteria and strengthened of ABET competencies during the PBL

The same evaluation criteria were used in all subjects. In addition, at the end of the second semester a global document and a final presentation in front of a jury were delivered gathering in a comprehensive way and with a logical structure all the work done. Evaluation criteria and its relative importance are: (i) technical quality of the deliverables (35%), (ii) intermediate oral and final presentations of each subject (25%), (iii) development of ABET competencies (15%), (iv) creativity and innovation of the proposals (5%) and (v) global document and final presentation (Fig. 3) (20%, the score obtained will correspond to 20% of the grade for each of the subjects participating on the subject).

Several ABET competencies should be strengthened and measured to ensure that students achieve a solid educational foundation. These were the ability to communicate effectively, the ability to function on multidisciplinary teams and the ability to analyse different socio-technical alternative based on eco-

Table 2. Measurement scheme of obtained competencies in the course

Competence	When to measure	How to measure	Who
Ability to communicate effectively.	During intermediate and final presentations in each of the subjects. In the final presentation front of the jury.	Rubric.	Professor of each subject and final presentation jury.
Ability to function on multidisciplinary teams.	During the first team work session and in the last week. At the end of each subject.	Rubric. Allocation of points between students in each group.	Professor of each subject. Students.
Ability to analyse different socio-technical alternative based on economic, social and environmental aspects.	In the written document and in intermediate and final presentations en each of the subjects an alternative analysis of socio-technical solutions must be included.	Rubric.	Professor of each subject.

nomic, social and environmental aspects. They were measured in all subjects during the whole process and analyzed to evaluate the learning outcomes of this experience on the MTHDC. The previous table (Table 2) shows the main aspects of the measurement of these competencies.

The assessment of selected ABET competencies (communicate effectively, function on multidisciplinary and international teams, analysis of different alternatives) has been done through rubrics, that can be consulted at the end of this paper (Table A.1, Table A.2 and Table A.3).

The Communication Competence Rubric (Table A.1.) was fulfilled for each student during the intermediate and final oral presentations of each subject by each professor and for each student during the final presentation in front of the jury. The Team Work Competence Rubric (Table A.2) was also fulfilled obtaining two measurements per group. Measurements were obtained based on team work sessions done in each subject, specifically in the first team work session and in the last week. In addition, some points were allocated between students in each group, giving them the possibility to assess their own performance on this competence. In the case of the Alternatives Analysis Competence Rubric (Table A.3) one measurement was obtained for each group.

3. Results and discussion

3.1 Results on the strengthened of ABET competencies during the whole PBL

3.1.1 Communication competence

Communication competencies factors (CCF) measure the ability to communicate effectively. Measurements were done by a professor in the intermediate and final presentations in each subject and in the final presentation from the jury.

The factors are:

CCF1: The student clearly organizes the content of the presentation.
CCF2: The student uses the adequate oral style to ease the audience understanding.
CCF3: The student appropriately uses the oral communication techniques.
CCF4: The student uses graphics and other technical resources to effectively communicate the information.

Two analysis of the variance have been done in order to know if there is a significant statistical difference for each communication competence factor between intermediate and final presentations and for the results of the different communication competence factors.

Table 3. Results for CCF by type of presentation

	Intermediate presentations	Final presentations	Total
CCF1			
Mean	3.0	3.3	3.2
Standard Error	0.11	0.08	
Lower Limit	2.9	3.2	
Upper Limit	3.2	3.4	
CCF2	3.0	3.2	3.2
Mean			
Standard Error	0.12	0.08	
Lower Limit	2.9	3.1	
Upper Limit	3.2	3.3	
CCF3	3.0	3.2	3.1
Mean			
Standard Error	0.12	0.08	
Lower Limit	2.82	3.1	
Upper Limit	3.1	3.3	
CCF4	2.9	3.5	3.3
Mean			
Standard Error	0.11	0.08	
Lower Limit	2.7	3.4	
Upper Limit	3.0	3.6	

In the first case, the P-value test was done for each factor of communication competence factor between intermediate and final presentations. For the CCF1, CCF2 and CCF3, the type of presentation (intermediate or final) has not a statistically effect on the different communication competencies at the 95% confidence level, since the P-values are higher than 0.05 in the three factors (for CCF1 is 0.0753, for CCF2 is 0.1703 and for CCF3 is 0.1378). For the CCF4, the type of presentation has a statistically effect on this communication competence, since the P-value is lower than 0.05 (0.0000).

As it is shown in the Table 3, even in the cases where there is no statistical significance, results of communication competencies are better in final than in intermediate presentations, making the performance satisfactory in all cases. It could be assumed that students have improved their communication skills thanks to the PBL methodology; especially in the case of CCF4 (The student uses graphics and other technical resources to effectively communicate the information).

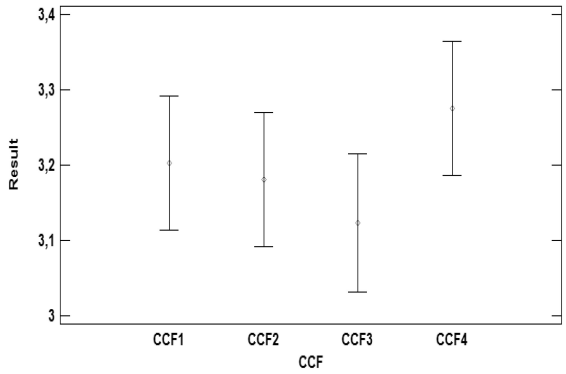
In the second case, the P-value test was done for results of the different communication competence factors. Since the P-value is higher than 0.05 (0.4319), this factor does not have a statistical effect on the result of the different communication competencies at the 95% confidence level. In all cases (Table 4 and Graphic 1), students' performance is satisfactory.

3.1.2 Team work competence

Team work competence factors (TWCF) measure the ability to work on multidisciplinary teams.

Table 4. Results of communication competencies

	Mean	Stnd. Error	Lower Limit	Upper Limit
CCF1	3.2	0.06	3.1	3.3
CCF2	3.2	0.06	3.1	3.3
CCF3	3.1	0.07	3.0	3.2
CCF4	3.3	0.06	3.2	3.4
Total	3.2			



Graphic 1. Results of communication competencies.

Measurements were done by professors of each subject during the first team work session and at the end of each subject. As in the previous case, an analysis of the variance has been done with the aim to know if there is significant statistical difference for each team work competence between the start and the end of the PBL and for the results of the different team work competencies factors.

The factors are:

TWCF1: The students participate in the meetings contributing with their knowledge and skills to achieve the goals.
TWCF2: The written document has been done as a group; it's coherent and has a logical structure.
TWCF3: Every student is capable of explaining the project and all the work that was done to achieve the goals.

The P-value test was done for each factor of team work competence between the start and the end of the PBL. Since the P-values are higher than 0.05 in the three factors (for TWCF1 is 0.8167, for TWCF2 is 0.3097 and for TWCF3 is 0.1442), the moment does not have a statistical effect on the different team work competencies at the 95% confidence level. In any case, groups have improved their performance in TWCF2 and TWCF3 during the PBL (results are presented in Table 5).

Also, the P-value test was done for the results of the different team work competence factors. In this case, since the P-value is higher than 0.05 (0.1687), the factor does not have a statistical effect on the result of the different team work competencies at the 95% confidence level. The different groups have similar performance (Table 6 and Graphic 2) on the different factors and it is satisfactory in all cases.

3.1.3 Alternatives analysis competence

Alternative analysis competence factors (AACF) measure the ability to analyse different socio-technical alternative based on economic, social and environmental aspects. Measurements were done by professors in each subject based on the written document and intermediate and final presentations.

The factors are:

AACF1: The economic analysis of the different alternatives has been realised with appropriate techniques and the pursued objectives with it have been achieved.
AACF2: The analysis of social implications of the different alternatives has been realised with appropriate techniques and the pursued objectives with it have been achieved.
AACF3: The analysis of the environmental aspects of the different alternatives has been realised with appropriate techniques and the pursued objectives with it have been achieved.
AACF4: The work done has correctly analysed the different alternatives globally, based on economic, social and environmental criteria, allowing the students to obtain valid conclusions.

An analysis of the variance has been done to the results of alternative analysis competencies factors to know if there is significant statistical difference between them.

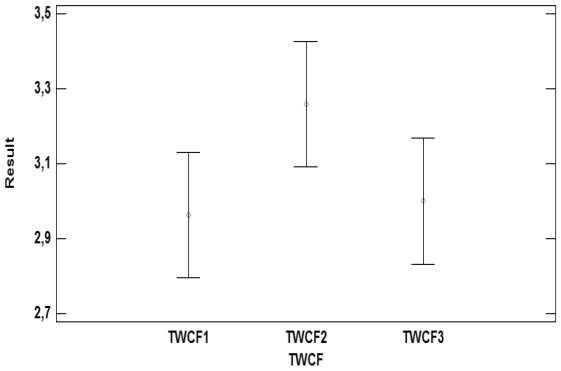
The P-value test was done for the results of alternative analysis competencies factors. Since the P-value is lower than 0.05 (0.0058) the factor had a statistical effect on the result of the different alternatives analysis competencies at the 95% con-

Table 5. Results for TWCF depending on the moment

	TWCF1				TWCF2				TWCF3			
Moment	Mean	Stnd. Error	Lower Limit	Upper Limit	Mean	Stnd. Error	Lower Limit	Upper Limit	Mean	Stnd. Error	Lower Limit	Upper Limit
First week	3.0	0.26	2.6	3.4	3.1	0.17	2.9	3.4	2.8	0.18	2.5	3.0
End of the subject	3.0	0.18	2.7	3.2	3.3	0.12	3.2	3.5	3.1	0.12	2.9	3.3
Total	3.0				3.3				3.0			

Table 6. Results for team work competencies

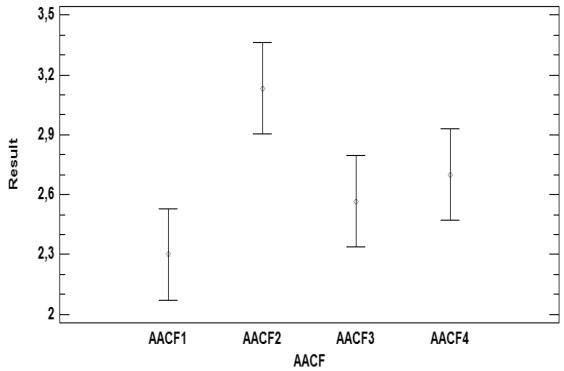
	Mean	Stnd. Error	Lower Limit	Upper Limit
TWCF1	3.0	0.12	2.8	3.1
TWCF2	3.3	0.12	3.1	3.4
TWCF3	3.0	0.12	2.8	3.2
Total	3.0			



Graphic 2. Results for team work competencies

Table 7. Results for alternatives analysis competencies

	Mean	Stnd. Error	Lower Limit	Upper Limit
AACF1	2.3	0.16	2.1	2.5
AACF2	3.1	0.16	2.9	3.4
AACF3	2.6	0.16	2.3	2.8
AACF4	2.7	0.16	2.5	2.9
Total	2.8			



Graphic 3. Results for alternatives analysis competencies.

fidence level. Results show (Table 7 and Graphic 3) that in general, students have problems and need to improve their performance when doing alternative analyses, except when analysing social implications. In the case of economic analysis, results are the worst among these factors being the one that students need to improve in greater extension.

3.2 Perception of professors and students about the PBL

During the 6 month duration of the PBL in the MTHDC, a constant follow-up was done, both with the different professors and students. Professors had regular coordination meetings during different phases of the PBL, before it started in order to plan, prepare and organise it, and during the development of the PBL. Students were informed about the new methodology one month prior to starting and regular follow-ups between a student representative and the coordinator of the PBL was done.

During these meetings professors and students perceptions were collected with the aim of solving different problems that appeared during the PBL and to improve the experience for following years. At the end of the process, a questionnaire was answered by the 11 professors involved in the PBL subjects and by the 12 students of the MTDHC in the academic year 2014/15.

3.2.1 Level of achievement of proposed objectives

As it was stated before, apart from the typical objectives considered under a PBL methodology and the specific objectives included in the Master's Degree programme, the methodology aimed to achieve some specific objectives for students, at internal level and in relation with the support of IABS. The different proposed objectives have been scored in the questionnaire answered by professors and students according to the extension in which the objective was achieved (from 0 or not achieved in any extension, up to 10 or completely achieved).

First of all, the perception of the level of achievement of the proposed objectives for students was answered by professors and students. As it is shown in Table 8, professors' perception is higher than students' perception in all the cases. For students, the perception is that the PBL methodology has not achieved the objective of working on a real problem and looking for applicable solutions based on real data and with feedback from one organisation based on the area of concern. For professors, this objective is also perceived as the one achieved in less extension.

In Table 9 results of professors' perception of level of achievement of proposed internal objectives are shown. Results show that professors perceived that they have been widely achieved in all cases, between 70–80%. This shows the PBL methodology has improved the MTDHC for the future in different areas. The continuous meetings done among participating professors, all of them from different engineering areas, have widely contributed to reinforce the relationships between them and to strengthen their capabilities to work with an interdisciplinary approach. This is fundamental to develop successful projects in developing countries

Table 8. Level of achievement of proposed objectives for students in the PBL methodology in the MTHDC

	Professors' perception		Students' perception	
Proposed objectives for students in the PBL methodology	**Average**	**Standard deviation**	**Average**	**Standard deviation**
To strengthen the ability to function on multidisciplinary and international teams as needed for good performance when working in developing countries.	7.8	1.6	5.4	3.1
To understand how problems are interrelated on the provision of basic services in developing countries.	8.0	1.4	6.1	2.7
To be able to analyse problems and technical solutions with a human and sustainable development perspective.	7.0	2.1	6.6	1.1
To work on a real problem and look for applicable solutions based on real data and with feedback from one organisation based on the area of concern.	6.9	2.6	4.0	3.1

Table 9. Level of achievement of proposed internal objectives in the PBL methodology in the MTHDC

	Professors' perception	
Proposed internal objectives in the PBL methodology	**Average**	**Standard deviation**
To strengthen the training offer of the MTHDC with an innovative methodology.	7.7	2.3
To reinforce the relationships between lecturers and researchers from different engineering areas and faculties.	7.6	1.6
To strengthen the capabilities of lecturers and researchers from different engineering areas and faculties to work together, both for teaching and research, with an interdisciplinary approach.	7.3	1.2
To fortify the strategic relationship between itdUPM and IABS.	8.0	1.7

where different problems are normally interconnected between them.

In addition, the process has achieved to fortify the relationship between itdUPM and IABS what is really important due to both organisation conceived it as a strategic relationship in the long term.

Regarding the proposed objectives in relation with the support of IABS, results show (Table 10) that professors and students perception about the level of achievement is not very good. During the process the support of IABS was really important for the correct development of the whole process but the engagement needs to be improved. In the initial phase, when the global project was planned and the specific information of the local reality needed to develop the specific project in each subject was gathered, professors perceived that support of IABS was good. On the contrary, students' perception of the achievement in this phase is really low. During the development of the PBL, the objectives were not achieved. Both professors and students perceived that the support of IABS to interchange information and to follow-up the solutions proposed by the students was not enough. The participation of IABS in the final jury is perceived by both groups as the best contribution.

3.2.2 Analysis of difficulties during the PBL

A previous study from the Technical University of Madrid [14] did a systematic detection of difficulties and their causes in PBL experiences in the Machine Engineering Division. Main factors that can limit

Table 10. Level of achievement of proposed objectives in relation with the support of IABS during the PBL in the MTHDC

Proposed objectives in relation with IABS during the PBL	Professors' Perception		Students' perception	
	Average	**Standard deviation**	**Average**	**Standard deviation**
Support in the planning of the global project related to the local situation	5.9	2.3	4.4	2.6
Support in the planning of the individual project in each subject related to the local situation	5.0	2.7	3.4	1.7
Gathering of specific information of the local reality	6.1	1.8	–	–
Meeting to interchange information	4.0	2.6	–	–
Follow-up of solutions proposed by the students	3.2	3.1	3.8	1.4
Participation on the final evaluation session	6.7	3.3	5.5	3.0

PBL experiences were selected based on the results of this study, choosing those with a score higher than 8 according to relevance and complexity. Difficulties were grouped following the same criteria (''planning and preparation'', ''organisation'', development'' and ''assessment'') and adapted to the specific PBL experience presented in this paper.

The different selected difficulties have been scored in the questionnaire answered by professors according to difficulty found on each case (from 0 or any difficulty, up 10 or maximum difficulty). In addition, students scored in which extension the difficulties were overcome during the process (from 0 or not overcome in any extension, up to 10 or completely overcome). Results are presented in Table 11.

Perceptions from professors and students differ remarkably. Professors considered that difficulties have varied from medium to high difficulty but no one is from maximum difficulty. On the contrary, students considered that none of these difficulties have been correctly overcome. Also, students did not accept the PBL methodology as something positive.

For professors, planning and preparation activities presented the greatest difficulties. ''Designing a coherent global project where all the different subjects could be inserted'' and ''designing individual projects in each subject related to the global project'' were perceived as very difficult. The different types of subjects make that the approach in each case varied in great extension. ''Technical'' subjects had plenty of problems to insert their more specific projects on the comprehensive approach and to find clear relationships with the ''general'' subjects.

''Planning the global and individual projects to fit the time allocated to the subject'' and ''project coordination and timescales in the individual subjects compared to the other participating subjects and the global project'' were also perceived more

Table 11. Analysis of difficulties during the PBL

Main difficulties during the PBL	Professors perception of the grade of difficulty		Students perception of the overcoming of the difficulty	
	Average	Standard deviation	Average	Standard deviation
Planning and preparation				
Designing a coherent global project where all the different subjects could be inserted.	7.6	1.6	2.3	1.8
Designing individual projects in each subject in a way that it was able to answer the needs of the global project and to correctly integrate it in the global project.	6.9	2.2	2.6	1.3
Preparing projects of equivalent difficulty and scope in all the subjects.	6.3	2.7	3.8	2.9
Achievement of learning outcomes of each individual subject with the new methodology.	4.9	2.8	2.1	1.6
Designing of the same evaluation system for all subjects.	5.2	3.2	2.4	2.8
Planning the global and individual projects to fit the time allocated to the subject.	6.8	1.8	1.4	1.6
Searching for a realistic approach (based on a 'real' problem) but feasible for students.	6.3	3.3	4.4	1.8
Organisation				
Students' acceptance of the proposed 'PBL' methodology as something positive.	7.7	1.1	3.5	2.0
Project coordination and timescales in the individual subjects compared to the other participating subjects and the global project.	6.3	1.9	2.6	2.5
Development				
Setting milestones throughout the process in coordination with the other subjects.	5.5	2.7	1.1	1.4
Taking action to adapt students starting-out levels.	5.4	1.9	-	-
Coordinating the development between the individual subject and the other participating subject.	4.7	2.3	1.75	1.91
Motivation and follow-up to avoid deviations in the expected results.	6.1	1.5	3.5	2.0
Motivation and follow-up to avoid deviations in the timescales.	5.6	2.0	3.7	2.1
Assessment				
Setting an adequate system to evaluate knowledge.	5.3	2.6	2.5	3.0
Application of the competencies measurement system.	6.0	3.0	2.9	3.4
Setting an adequate system to individualise group experiences.	6.9	2.6	-	-
Detecting, controlling and solving unacceptable conduct.	5.0	3.3	1.2	2.0

difficult than other factors. Both professors and students recognise that the time allocated to develop a coherent global project was higher than the time allocated for the specific projects in each subjects. This problem has led to the perception by both groups that some learning outcomes, mainly on "technical subjects", were not achieved. Lastly, setting an adequate system to individualise group experiences was also found difficult by professors.

4. Conclusions

The work presented in this paper analysed the process done within the MTHDC during more than six months. An ambitious project based learning experience was set, working simultaneously with the same project in 8 subjects and based on a real context in Brazil with the support of a local NGO. Results on strengthen of ABET competencies during the whole PBL and perceptions of professors and students about different aspects of the PBL were presented.

The experience has been successful in strengthening ABET competencies. In general, students' performance is satisfactory in communication and team work competencies, with an improvement during the PBL experience. In the case of alternative analysis competencies, students need to improve their performance, except on the analysis of social implications. Based on these results, professors will introduce some changes in their respective subjects to help students to improve their capabilities to analyse alternatives based on different criteria.

The questionnaire done at the end of the experience shows that communication between professors and students needs to be improved. More efforts are needed to explain the aim and benefits of the PBL methodology compared with the previous learning paradigm of the MTHDC. Also, the involvement of IABS has to be reviewed and improved in order to really leverage the potential of this collaboration to link the academic experience with the real context. Regarding the PBL design, it is needed to review how to engage "general" and "technical" subjects between them and within the global project.

The experience was very interesting; with many lessons for future initiatives but it has not been a complete success. This study detected some positive and negative issues allowing the introduction of changes and corrective and preventive actions since the beginning of the PBL both for the UPM experience and other worldwide initiatives.

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References

1. J. L. Pérez-Benedito, J. Pérez-Alvarez and M. J. Casati, PBL in the teaching of design in Aeronautical Engineering: Application and Evolution of a Consolidated Methodology, *International Journal of Engineering Education*, **31**(1), 2015, pp. 199–208.
2. M. Friesen and K. L. Taylor, Perceptions and experiences of industry co-operators in project-based design courses, *International Journal of Engineering Education*, **23**(1), 2007, pp. 114–119.
3. A. M. Hasna, Problem based learning in engineering design in SEFI 36th Annual Conference, European Society for Engineering Education, Aalborg University, Denmark, July 2008.
4. R. Hadgraft, Problem-based learning: A vital step towards a new work environment, *International Journal of Engineering Education*, **14**(1), 1998, pp. 14–23.
5. R. Gordon, Balancing real-world problems with real-world results, *Phi Delta Kappan*, **79**(5), 1998, pp. 390–393.
6. L. D. Feisel and A. J. Rosa, The role of the laboratory in undergraduate engineering education, *Journal of Engineering Education*, **94**(1), 2005, pp. 121–130.
7. J. Jordana and F. J. Robert, A Course on Digital Electronics Based on Solving Design-Oriented Exercises by Means of a PBL Strategy, *International Journal of Engineering Education*, **31**(1), 2015, pp. 238–247.
8. S. A. Setia, B. Z. A. Zachariah, P. H. Ananthanarayanan, M. R. Radhika, M. Kavitha and T. Prashanth, Case Based Learning Versus Problem Based Learning: A Direct Comparison from First Year Medical Students' Perspective, *Webmed Central Medical Education*, **2**(6), 2011, pp. 1–14
9. I. De los Rios-Carmenado, F. Rodríguez López, C. Pérez García, Promoting Professional Project Management Skills in Engineering Higher Education: Project-based Learning (PBL) Strategy, *International Journal of Engineering Education*, **31**(1), 2015, pp. 184–198.
10. H. P. Yueh, Y. L. Liu and W. Lin, Fostering Interdisciplinary Learning in a Smart Living Technology Course through a PBL Approach, *International Journal of Engineering Education*, **31**(1), 2015, pp. 220–228.
11. C. Zhou, A. Kolmos and J. F. D. Nielsen, A problem and project-based learning (PBL) approach to motivate group creativity in engineering education, *International Journal of Engineering Education*, **28**(1), 2012, pp. 3–16.
12. N. Fang, Improving engineering students' technical and professional skills through project-based active and collaborative learning, *International Journal of Engineering Education*, **28**(1), 2012, pp. 26–36.
13. K. B. Codur, S. Karatas and A. H. Dogru, Application of project-based learning in a theoretical course: process, difficulties and recommendations, *International Journal of Engineering Education*, **28**(1), 2012, pp. 17–25.
14. A. Diaz Lantada, P. Lafont Morgado, J. M. Muñoz-Guijosa, J. L. Muñoz Sanz, J. Echávarri Otero, J. Muñoz García, E. Chacón Tanarro and E. De la Guerra Ochoa, Towards successful project-based teaching-learning experiences in Engineering Education, *International Journal of Engineering Education*, **29**(2), 2013, pp. 1–15.
15. Development Programme United Nations, *Making new technologies work for human development*, Oxford University Press, 2001.
16. Sustainable Development Goals, https://sustainabledevelopment.un.org/?menu=1300, Accessed 25 January 2016.
17. C. Mataix, and J. Carrasco, Capítulo 7: Ciencia, Tecnología y Sociedad, in J. A. Alonso (ed), *Movilizando los recursos y los medios de apoyoparahacerrealidad la Agenda de Desarrollo Post-2015,* vol. 5, Documentos de Trabajo 2015, SGCID, Madrid, 2015, pp. 46–51.
18. Master's Degree in Sustainability Science and Technology of the Technical University of Catalunya, http://www.upc.edu/

master/fitxa_master.php?id_estudi=296&lang=en, Accessed 20 January 2016.
19. Global Human Development Program of the Georgetown University, http://ghd.georgetown.edu/core-courses, Accessed 20 January of 2016.
20. International Development Postgraduate Courses of the Institute of Development Studies, http://www.ids.ac.uk/study/postgraduate-courses, Accessed 20 January 2016.
21. Master's Degree in Energy Policy for Sustainability of Sussex University, http://www.sussex.ac.uk/spru/study/2016/taught/33106, Accessed 20 January 2016.
22. Master's Degree in Water Security and International Development of the University of East Anglia, https://www.uea.ac.uk/study/postgraduate/taught-degree/detail/msc-water-security-and-international-development, Accessed 20 January 2016.
23. Master's Degree in Development Economics and Political Economy of the Massachusetts Institute of Technology, http://economics.mit.edu/graduate/courses/development, Accessed 20 January 2016.
24. Master's Degree in Innovation for Sustainable International Development of Sussex University, http://www.sussex.ac.uk/spru/study/2016/taught/33107,Accessed 20 January 2016.
25. J. MazorraAguiar, M. Pérez Sonora, L. Fernández García, A. C. Ventura and J. Lumbreras Martín, Caracterizando la gestión del recursohídrico en lasescuelasrurales del semiáridoalagoano: propuesta de unmodelo de evaluación, *Documentación social*, **173**, 2014, pp. 205–228.
26. L. Fernández, C. Galdaniand J. Lumbreras, *Avaliação de cisternasescolares no semiáridoalagoano,*SérieCooperação-Brasil—Espanha — ProgramaCisternas BRA 007-B Vol. 6, Editora IABS, Brasilia DF, 2015.
27. Master's Degree on Technology for Human Development (MTHDC) of the Technical University of Madrid (UPM), http://www.itd.upm.es/master/guia-completa/, Accessed 20 January 2016.

Annex: Competence Rubrics and Curriculum of the MTHDC

Table A.1. Communication Competence Rubric

Communication Competence Factors (CCF)	**Achievement level**			
	Unsatisfactory (1)	**Need improving (2)**	**Satisfactory (3)**	**Excellent (4)**
CCF1: The student clearly organizes the content of the presentation	The presentation is disorganized and lacks of a logic structure. It is not organized using sections, titles, points, etc. The audience just can follow it making a great effort and it is difficult to identify the main message.	The presentation is structured in a confusing way. The organization by sections, titles, points, etc. is not clear. The audience is not able to understand it adequately and have to make some efforts to follow it.	The presentation is in general clear, although some points are not well structured o are confusing. The organisation in sections, titles, points, etc. is clear although some aspect could be improved. The audience can follow adequately although they have to make some effort in some moments.	The structure of the presentation is clear, coherent and logic. The audience can easily follow and understand the presentation.
CCF2: The student uses the adequate oral style to ease the audience understanding.	The vocabulary used and the overall level of the communication is not adapted at all to the audience.	In many aspects, the presentation is neither well structured nor oriented to the audience. Ideas or vocabulary are not adequate for the previous knowledge of the audience.	The style is adequate for the audience, although some ideas or vocabulary are too simple or complicated for the audience.	The presentation is perfectly adequate for the audience, including the style, ideas and vocabulary used.
CCF3: The student appropriately uses the oral communication techniques.	Presentation is done under nervous status or supported by notes. Oral techniques are not used. The way to communicate does not help at all to maintain the attention of the audience.	Presentation is not well supported by communication techniques. The student does not look to the audience, does not modulate the voice, does not reinforce the verbal language with corporal communication language and does not avoid the use of informal language.	Oral communication techniques are generally well used, although sometimes the volume and the oral expression are not correct. Also, sometimes the student does not look to the audience.	Message is reinforced, getting the audience attention and using adequately the oral communication techniques. The student looks to the audience, modulates the voice, reinforces the verbal language with corporal communication language and avoids the use of informal language.
CCF4: The student uses graphics and other technical resources to effectively communicate the information.	Neither graphic nor additional resources are used to support the communication.	Graphic and/or other resources are poorly used or inadequately applied (bad quality figures, graphics do not help to analyze and interpret the information).	Graphics and/or other resources are commonly used, but these resources are not always adequate for the content of the presentation.	Graphics and/or other resources are perfectly used and in a professional manner. These resources make easy the analysis and interpretation of the information.

Table A.2. Team Work Competence Rubric

Team Work Competence Factor (TWCF)	Achievement level			
	Unsatisfactory (1)	**Need improving (2)**	**Satisfactory (3)**	**Excellent (4)**
TWCF1: The students participate in the meetings contributing with their knowledge and skills to achieve the goals.	Most of the team members' attitude is passive; they do not join in the discussions and contribute with their own ideas. The group does not work, they require constant support from the professor and they do not reach the established goals.	One or more members of the team have a passive attitude and do not join in the discussions; they do not collaborate to reach the group goals. The goals are reached by other teammate efforts.	All the students participate in the tasks, but some of them are less involved or only participate in simple tasks (taking notes, reaching for equipment, etc.)	All students have the same level of engagement; they all participate and contribute in order to achieve the group's goals.
TWCF2: The written document has been done as a group; it is coherent and has a logical structure.	The document presents a mix of styles and formats. There is no coherence between different sections of it (repetitive content, content with no logical sequence, etc.)	In some cases, different sections of the document are not well connected and there are several inconsistencies in style, format, content or presentation.	The document shows a concrete line of thought and generally establishes connections between all the different sections. In some cases there are small discrepancies in format or style.	The document shows a concrete line of thought, the structure is logic and all sections are well connected. The format and style through the document is the same.
TWCF3: Every student is capable of explaining the project and all the work that was done to achieve the goals.	It is clear during the presentation that some students have no knowledge of some sections of the project or they are not able to link the different parts of it. Generally most of the members have no vision of the whole project.	In some cases, one or more of the students have difficulties explaining or answering questions about specific sections of the project. Only some of the students seem to have worked in all aspects of the project and have a vision of the work done as a whole.	All the members of the group are capable of explaining fluidly all sections of the project, but there is a discrepancy in the levels of knowledge between team members. Some student of the group seems to have lower participation and overall vision of the project than the others.	During the presentation every member of the group is capable of explaining and answering questions about all the sections of the project. All members show knowledge of the project as a whole.

Table A.3. Alternatives Analysis Competence Rubric

Alternatives Analysis Competence Factor (AACF)	Achievement level			
	Unsatisfactory (1)	**Need improving (2)**	**Satisfactory (3)**	**Excellent (4)**
AACF1: The economic analysis of the different alternatives has been realised with appropriate techniques and the pursued objectives with it have been achieved.	The work does not have any economic analysis or this has been done in a superficial way.	The work has an economic analysis, but it is not enough to take decisions.	A good economic analysis has been done. This analysis allows obtaining valid conclusions to justify the adopted alternative.	A deep economic analysis has been done. This analysis allows obtaining valid conclusions to justify the adopted alternative. The analysis even allows proposing key issues to ensure the economic sustainability of the adopted alternative.
AACF2: The analysis of social implications of the different alternatives has been realised with appropriate techniques and the pursued objectives with it have been achieved.	The work does not have any analysis of social implications or this has been done in a superficial way.	The work has an analysis of social implications, but it is not enough to take decisions.	A good analysis of social implications has been done. This analysis allows obtaining valid conclusions to justify the adopted alternative.	A deep analysis of social implications has been done using a proven methodology. This analysis allows obtaining valid conclusions to justify the adopted alternative. The analysis even allows proposing corrective measures to avoid social conflict derived from the adopted solution.

AACF3: The analysis of the environmental aspects of the different alternatives has been realised with appropriate techniques and the pursued objectives with it have been achieved.	The work does not have any analysis of the environmental aspects or this has been done in a superficial way.	The work has an analysis of the environmental aspects, but it is not enough to take decisions.	A good analysis of the environmental aspects has been done. This analysis allows obtaining valid conclusions to justify the adopted alternative.	A deep analysis of the environmental aspects has been done using a proven methodology. This analysis allows obtaining valid conclusions to justify the adopted alternative. The analysis even allows proposing corrective measures to avoid environmental impacts derived from the adopted solution.
AACF4: The work done has correctly analysed the different alternatives globally based on economic, social and environmental criteria, allowing the students to obtain valid conclusions.	The work does not have any alternatives analysis or this has been done in a superficial way.	The work has an alternatives analysis where all criteria have not been included in the same extension. The alternatives analysis has been done in a superficial way for all the criteria and it is not enough to take decisions.	A good alternatives analysis has been done. All criteria have been included in the same extension and in a correct way. This analysis allows obtaining valid conclusions to justify the adopted alternative.	A deep alternatives analysis has been done for all the criteria, being able to interrelate them. This analysis allows obtaining valid conclusions to justify the adopted alternative. Proven methodologies have been used for each of the criteria.

Table A.4. Curriculum of the Master's Degree on Technology for Human Development (MTHDC) of the Technical University of Madrid (UPM) [27]

Semester	Subject	Type of Subject	ECTS
First	Theory and Policy of Development	Compulsory	6
	International Aid System	Compulsory	6
	Network and Partnerships for development	Compulsory	6
	Aid Cycle Methodologies	Compulsory	6
	Basic Techniques of Quantitative and Qualitative Research Methods	Optional	6
	Food Security Value Chain	Optional	6
Second	Territorial Development	Compulsory	5
	Geographic Information Systems (GIS)	Compulsory	5
	Water and Human Development	Compulsory	4
	Energy and Human Development	Compulsory	4
	Agro-forestry Systems, Agriculture and Human Development	Compulsory	4
	Constructive Technologies and Basic Habitability	Compulsory	4
	ICT for Human Development	Compulsory	4
Third	Professional Internship	Compulsory	13
	Master's Degree Final Project	Compulsory	15
	Master's Degree Final Project Jury	Compulsory	2
TOTAL			90

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