

# Integration of three instructional design models within the organization of PBL activities

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## Abstract

This work is aimed at defining a method to design courses based on Project Based Learning methodology. This proposal is specially focused on those academic contexts in which instructors are starting to use this methodology and students are not used to dealing with ill-structured projects, and consequently they could find important difficulties in its implementation. To reach this goal, this method is based on several instructional design models, learning theories and PBL principles. In particular, the method faces three fundamental issues in active learning and especially in PBL: Students' Motivation, Supporting Students' Work and Autonomous Working. Engaging instructors to follow these models when they are designing the course facilitates the subsequent success during the course implementation. The method has been put into practice in three courses, where first results seem to be satisfactory according to a survey conducted by the University. Results of this survey over for the last six years have been analysed. Besides the description of the method, we present a collaborative online tool that supports it.

**Keywords:** Instructional design, course design, students' motivation, PBL support

## 1 Introduction

Project Based Learning (PBL) has spread across countries and disciplines over the last decades. In particular it has demonstrated to be appropriate to engineering studies. Probably, for this reason every year more and more teachers join this methodology. Nevertheless, in some experiences PBL is used in an intuitive way based on the teaching experience of instructors, but unfortunately without considering basic principles or formal methods. Consequently, expected results are not achieved. According to our experience, the better results in PBL are achieved when some instructional design methods, developed by experts, are taken into account to organize the PBL course or activity.

This problem appears to be especially important with freshman students, who do not have large experience with facing ill-structured problems. Just to illustrate, we can describe the recent case of Programming Workshop taught at Universidad Politécnica de Madrid during the first semester in two degrees: Computer Science Engineering and Software Engineering. This workshop lasts one semester. Students have to solve a programming project while they are following a first programming course. Results were disappointing. As far as teachers' opinion in concerned, they seem to have a clear idea about the main drawback they found: "The main problem was the lack of knowledge about programming language and programming practice.

This workshop takes place in the same semester than Fundamentals of Programming. Although the workshop starts later, students follow both courses simultaneously during the second half of the semester. An additional problem is organization. Students do not plan adequately their time and do not organize tasks among team members. On the other hand, students enjoyed developing a project and they end up learning about programming”.

But, not only happens this problem in first semesters. In some academic contexts, even more experimented students are not used to dealing with this kind of problems, therefore they feel lost and end up rejecting the methodology. We had a similar experience in the course Operating Systems, taught during the fifth semester. Precisely, this is the course where we put into practice the method described in this paper and where we obtained the results presented in section 3. Jonassen summarize this issue in (Jonassen, 1997), “we cannot assume that learners are naturally skilled in problem solving, especially complex and ill-structured problems such as those required in most PBL programs”. Based in our experience, this issue is related to some of the most important drawbacks in PBL implementation.

There is a significant number of instructional design theories focused on organizing different issues of PBL activities that turn out helpful to overcome the difficulties above mentioned. In particular we highlight in this paper three models that work separately on three different aspects of instructional process: ARCS Motivational Model (Keller et al., 1982), Supporting PBL (Jonassen, 1999) and Autonomous Work (Rué, 2009). ARCS model was developed by J. Keller, who proposes to work on four areas to foster student motivation: capture the attention, demonstrate the relevance, create student confidence and facilitate students’ satisfaction. D. Jonassen theories about supporting students’ work on constructivist learning environments are used to design the support that instructors will provide to students during the learning process. Finally, J. Rué proposal helps us to organize the autonomous and directed work of students.

The aim of this paper is to describe a method to design courses (or activities) based en PBL methodology. This method leads instructors to design PBL courses by following several instructional design models, learning theories and PBL principles. This way, students will have more chance to achieve success in the project development and learning process. From our point of view, this method could be especially helpful in academic contexts in which instructors are starting to use PBL and students are not skilled in dealing with complex projects.

The method, described in detail in section 2, is divided into three phases: Definition of the problem, Support of student’s work and Organization of the course. Definition phase is mainly based on principles and characteristics of PBL, some learning theories and suggestions to design ill-structured problems. In Support phase we establish some relationships among the three instructional design models, then, leaned on these links, we propose a set of steps to design the course or activity. The third phase, Organization is not object of this paper, since it was described in previous works (Garcia et al., 2009). Anyway, we will link it with the present work in order to provide a general vision of the complete process.

Once the content of the course has been configured, every aspect of it (documents, references, planning etc.) can be incorporated into an online tool developed at the Computer Science School (Universidad Politecnica de Madrid). This tool is of use to both instructor and students (Garcia et al., 2014).

This process has been used to organize two courses: Operating Systems and Real Time Systems, both of them taught in the Computer Engineering degree. Some surveys reveal significant improvement in student opinion about subject organization, interest, learning and results. Likewise, it has been used to organize a first-year course, Programming Workshop, that is being taught during the spring semester in 2015.

This paper is structured as follows: Section 2 presents the description of the process, the steps and the theories in which it is based. It also includes an introduction to the online tool PBLT. Section 3 shows the main results obtained in some courses where this method was applied. Finally, in Sections 4 we present the main conclusions and future works.

## **2 Method**

### **2.1 Introduction**

There are a large number of proposals to design PBL activities. For instance, (Edutopia, 2012) specifies seven steps: Introducing the Driving Question; Introducing the Culminating Challenge; Developing Subject Matter Expertise; Doing the Culminating Challenge; Debriefing the Culminating Challenge; Responding to the Driving Question; Summative Assessment. L. M. Nelson (Nelson, 1999) focuses attention on collaborative problem solving issues, pointing out the organization of collaborative work. We find particularly interesting the process proposed by (Jonassen, 1997) to design ill-structured problems, which consists of seven steps: (1) Articulate the problem; (2) Introduce problem constraints; (3) Locate, select and develop cases for learners; (4) Support knowledge base construction; (5) Support argument construction; (6) Assess problem solutions.

Based on these ideas, we have divided the process into three general phases: Definition, Supporting and Organising. The goal of the first one is to develop the definition of the project, following the main PBL principles and meeting the characteristics of good problems. This definition includes not only the goals, but also other information that helps to articulate the project. Subsequently, Support phase is dedicated to prepare different learning activities and materials focused on facilitating project success. Finally, Organization phase assists in planning the teaching-learning activities throughout the semester. Each phase is based on several learning theories and tries to coordinate them in order to establish a general process to design courses based on PBL. Figure 1 displays these phases, which will be discussed in more detail in next sections.

### **2.2 Definition**

The goal of this phase is to obtain the first project definition, which includes the basic information about objectives, restrictions, resources etc. Nevertheless, we start by gathering some previous information: Learning Outcomes of the course, Professional Activities that are carried out in professional contexts related to the course matter and the Topic that we want our students to face. Regarding Professional Activities, (Jonassen, 1999) suggests that it is recommended to engage learners in solving authentic problems, where “authentic means that learners should engage in activities which present the same type of cognitive challenges as those in real world.

Then, the first Project Proposal is written, which specifies the topic, the main goals and the work that must be developed. This proposal is prepared based on PBL principles formulated by Barrows (Barrows, 1996), summarized in (Kolmos, 2012) and increased in (De Graaff et al., 2003), which are recapped here: the use of problems as a starting-point for the acquisition and integration of new knowledge; new information acquired through self-directed learning; student-centered; learning in small groups; teachers acting as facilitators and guides rather than informants; activity-based learning, requiring activities involving research, decision-making and writing; inter-disciplinary learning, extending beyond traditional subject-related boundaries and methods; exemplary practice, ensuring that the benefits for the students are exemplary in terms of the objectives.

Then, we check if this proposal meets the Characteristics of a good problem, such as they are formulated in (Kolmos et al., 2009): It is engaging and oriented to the real-world; It is ill-structured and complex; It generates multiple hypotheses; It requires team effort; It is consistent with desired learning outcomes; It builds upon previous knowledge/experiences; It promotes development of higher order cognitive skills. According to these characteristics and PBL principles we would wonder if some changes are necessary in our proposal to improve it and make it more suitable for a PBL activity.

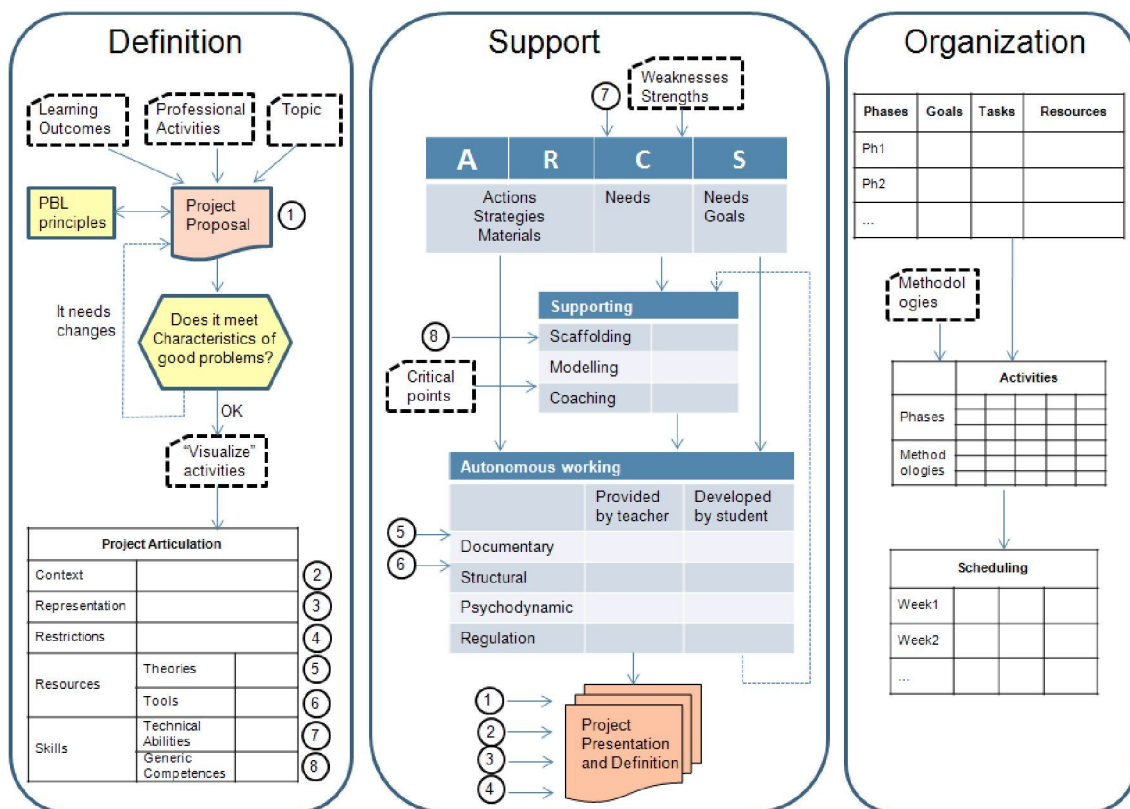


Figure 1: Schema of the method.

Once we have confirmed the Project Proposal is in tune with these characteristics and principles we move on to articulate the problem, according to (Jonassen, 1999). Nevertheless, before tackling this task, we find particularly helpful to “visualize” the activities that students will have to carry out when they will face the solution of the project. Sometimes, teachers prefer to implement an almost complete project, similar to the project that will be developed

by students. In both cases, the aim is to have an accurate idea about the student's work, its needs, difficulties and other issues that could help us to configure the project.

Project Articulation consists of five sections. First we describe the context of the project. The relationship of the problem with the social and professional context is an important issue for students to understand the relevance. According to (Jonassen, 1997), a representation or model of the problem can help students to understand the start point and the goals. Restrictions in the development as well as resources that will be needed, both theoretical ground and tools, are included in project articulation. Finally, we describe the skills that students will have to put into practice to develop the project. We distinguish between two kinds of skills. On the one hand technical abilities are those related to the specific discipline of the course. For instance, testing programs is an important technical skill in computer engineering. On the other hand Generic Competences are those that are transversal to every discipline, such as Team Working, Problem Solving or Written Communication. Regarding the later, we propose to include not only those competences that are required by the activities of the project, but also other competences that are specific goals of the degree curriculum.

We dealt with this problem in previous works (Perez-Martinez et al., 2014). In that work we proposed a method to integrate generic competences into curriculum in order to meet EHEE directions. The method consists in developing a map of generic competences according to some precedence relationship. Once the map is configured, it is projected into the semesters, so that a set of competences is attached to each semester. Afterwards, one or two competences are assigned to each subject. This way every subject is in charge of developing and assessing one or two generic competences specified in the curriculum. Competences are introduced into courses throughout the design of learning activities coordinated with the activities planned in the course. Including this issue in our method, we contribute to develop generic competences and consequently to integrate these skills into the curriculum. According to our experience, PBL is a suitable methodology to improve this kind of competences, such as teamwork, problem solving, analysis and synthesis or oral communication.

Numbers specified in Definition phase are used to identify those parts that will be used in other places. In Support phase, these numbers together with an arrow indicate where this information coming from Definition phase is used.

### **2.3 Support**

Initially, we gather some information about the main weaknesses and strengths of students who are going to develop the project. This information can be obtained from students who have followed the course in previous years or from previous courses in the curriculum. Weaknesses and strengths are important in designing the PBL support, in order to provide more assistance in those issues where student have more deficiencies.

ARCS model (Keller, 1982) is focused on promoting and maintaining student's motivation in the learning process. It proposes four steps: Attention, Relevance, Confidence and Satisfaction. First, Keller describes several ways for grabbing students' attention, using surprising and stimulating curiosity. Next, he introduces the relevance of the problem in order to increase learner's motivation. Confidence helps students to understand their likelihood for success. If

they feel they cannot meet the objectives or that the cost (time and effort) is too high, their motivation will decrease. Finally, Keller suggests several ideas to make students find satisfaction from their learning (Keller, 2010).

According to this model we enumerate and describe the actions, strategies and materials that we propose to use to catch student's attention. Similarly we describe the same elements to highlight and communicate to students the relevance of their project. Next, we think about students' confidence. In particular, we try to identify what are the needs of the students to gain confidence. At this point, information gathered about technical abilities and weaknesses provide important clues. Applying ARCS model finishes by identifying how we can promote students' satisfaction. What do our students need to feel satisfaction with the project? Based on this question we established some goals about this issue.

Before dealing with supporting strategies, we analyse the critical points of the project. We identify two types of critical points. First, those tasks or phases in which students find more difficulties, due to its complexity or the student's lack of experience. Second, some points can be cornerstones of the project, and consequently the viability or success of the project could depend on them.

Subsequently, we design the supporting material according to Jonassen model (Jonassen, 1999). This author identifies three types of supporting: scaffolding, modelling and coaching. Modelling is focused on the expert's performance. Behavioral modelling demonstrates how to perform the activities identified in the activity structure, it provides learners with an example of the desired performance. Cognitive modelling articulates the reasoning, decision making and argumentation that learners should use while engaged in each step of the activity. Coaching is focused on the learner's performance, it consists in accompanying, instructing and training a person to support him while achieving a specific personal or professional competence result or goal. Finally, Scaffolding is focused on the nature of task and the environment. It provides temporary frameworks to support learning and student performance beyond the learner's capacities.

In our case, first we propose to think about the points of the project (phases, tasks, activities etc.) in which students will need specific support. Most of these points can be identified by analysing the information elaborated about confidence needs, generic competences and critical points. Then, for each one of these points, we think about the most appropriate type of support (Scaffolding, Modelling or Coaching). The questions that we try to solve at this step is: What do our students need to overcome these points of the project?

Next step consists in organising the contents of the course, documents, tools, activities, tasks etc. In particular, we want to determine which contents will be provided by the teacher and which contents are responsibility of students through autonomous work. (Ru , 2009) classifies these issues into four classes: Documentary (Theories and information needed), Structural (Ideas, rules and tools to act or work), Psychodynamic (It is focused on the relationship among people, members of a group, related to the work) and Regulation (Information necessary to direct and asses or self-asses the work). For every item that we place in one of these classes we can decide if this item will be provided by the teacher or should be developed by the own students. We will place in the column "developed by teachers" those things that we know

student cannot do by himself (or in groups) or we do not want them to spend time on it. On the other hand, those things that students can do with some help of the teacher, they can do with some help of their mates or he can do by himself, will be placed in the column "Developed by the own students".

To integrate this model into our method, we propose to elaborate the table of Autonomous Working taking into account some information compiled in previous steps: actions, strategies and materials for catching attention and showing relevance; needs and goals to achieve student's satisfaction, all the materials described in supporting section, including any type (Scaffolding, Modelling and Coaching). Moreover, theoretical ground and tools that are needed in the project must be considered in this section. For each one of these items included in this table we think over the responsibilities of teacher and students. That means, we decide which facilities will be provided by teacher or which activities will be carried out by teacher. On the other hand, we define those materials and activities for which student will be responsible by themselves. This organization is made according to Rué's criteria. Once the table has been completed we suggest reviewing it in order to detect possible lacks in some of the sections. For instance, in some cases Structural and Regulation areas tend to have less items and we could consider to add new activities or facilities that could be useful to reinforce these issues.

To conclude the Support section, we deal with project presentation, which not only consists of those documents that will be handed out to students, but also activities carried out to engage students into the project and make them understand their work and responsibilities. At this step we find relevant some advices presented by (Ertmer, 2005) focused on how to present a project to students: Getting students thinking about the problem before the unit begins, planting seeds of curiosity weeks in advance; To "hook" students through the use of engaging opening scenario; Program activities to ease students into their new roles and responsibilities; Short problems used to introduce students to the problem-based method; Create "messing about" activities that help students to understand the specific sub-issues embedded within the problem. These actions are more effective than starting "cold" by researching an unfamiliar topic

In addition to this project presentation, we include a detailed definition of the project, so that students know the kind of work they have to develop, constraints, final goals, resources provided by teachers, working rules etc. Most of this information is elaborated from the information included in the table Autonomous Work. In this way, the final project definition, this that will be given to students, takes into account the elements elaborated in previous steps. These elements have been pondered according to instructional design theories and advisability in our project.

## **2.4 Organization**

This phase consists in planning and organizing the learning activities that will take place throughout the semester, so that we obtain a complete scheduling of the course. Although this process was presented in previous works (Garcia et al., 2009) we will summarize briefly it in order to provide a complete view of the method. This phase suggests seven steps to design an educational plan. It establishes relationships between every project phase and the educational

methodologies which can be used in the course (cooperative learning, laboratory, tutoring, etc). These relationships are established by means of the learning activities required in each phase (study, reflection, debate, testing, information management and tutoring). It helps to determine which methodology is the most appropriate for each phase of the project and establishes a relation between the work carried out in each phase and the learning activities required to complete it. In conclusion, we chose the most appropriate learning activities for each phase of the project. Finally, we place these learning activities in the semester schedule.

## **2.5 The tool PBLT**

In order to facilitate the use of this process, a cooperative tool that supports it has been developed at Computer Science School (Universidad Politécnica de Madrid), called PBLT. This tool consists of two parts. Firstly teachers use it to design course contents, taking into account the main principles of PBL methodology. Afterwards, once the course has been designed, teachers generate different instances of the course, so that every team of students is attached to an instance. Then, students use the same tool to organize their own project development, including aspects as planning, tasking, meetings or resource management. The most significant features of PBLT are: to integrate the activities of both teachers (design) and students (develop) in the same tool; to offer a collaborative environment for both, teachers' team and students' team; to allow different levels of depth in the project specification, in such a way that teachers can design a project at the desired level between well- and ill-structured; to take into account specific issues of academic contexts, like courses or lessons; to allow remote work.

Although this tool was originally presented in (Garcia et al., 2014), we describe briefly some features in order to show the support that this tool provides to the method described in this paper and the relationship between them. Figure 2 shows the windows through which teacher fills up the project definition and supporting materials, such as we have discussed in the first two phases of the method: Definition and Support. Moreover, it displays the graphic that represents the set of phases into which the project is divided and a calendar with important dates. This information is proved to students, who elaborate their own scheduling chronogram, shown in the last window.

## **3 Results**

The method described has been used to organize two courses over the last two years, Operating Systems (OS) and Real Time Systems (RTS), and we have observed important changes in student opinion throughout final course surveys. At the end of the term, students have to fill a survey elaborated by the UPM, which consists of 17 questions about the teachers and the subject. For this study we have analysed 4 items: I7-“I have improved my starting level, regarding the competences established in the course”; I11-“The teacher assistance is effective to learn”; I15-“The teacher achieves to arouse interest in the different topics studied during the learning activity”; I16-“The teacher facilitated my learning, and thanks to his/her help I improved my knowledge, skills or the way to face some topics”. This survey follows a Likert scale of 6 points (1=strongly disagree, 6=absolutely agree).



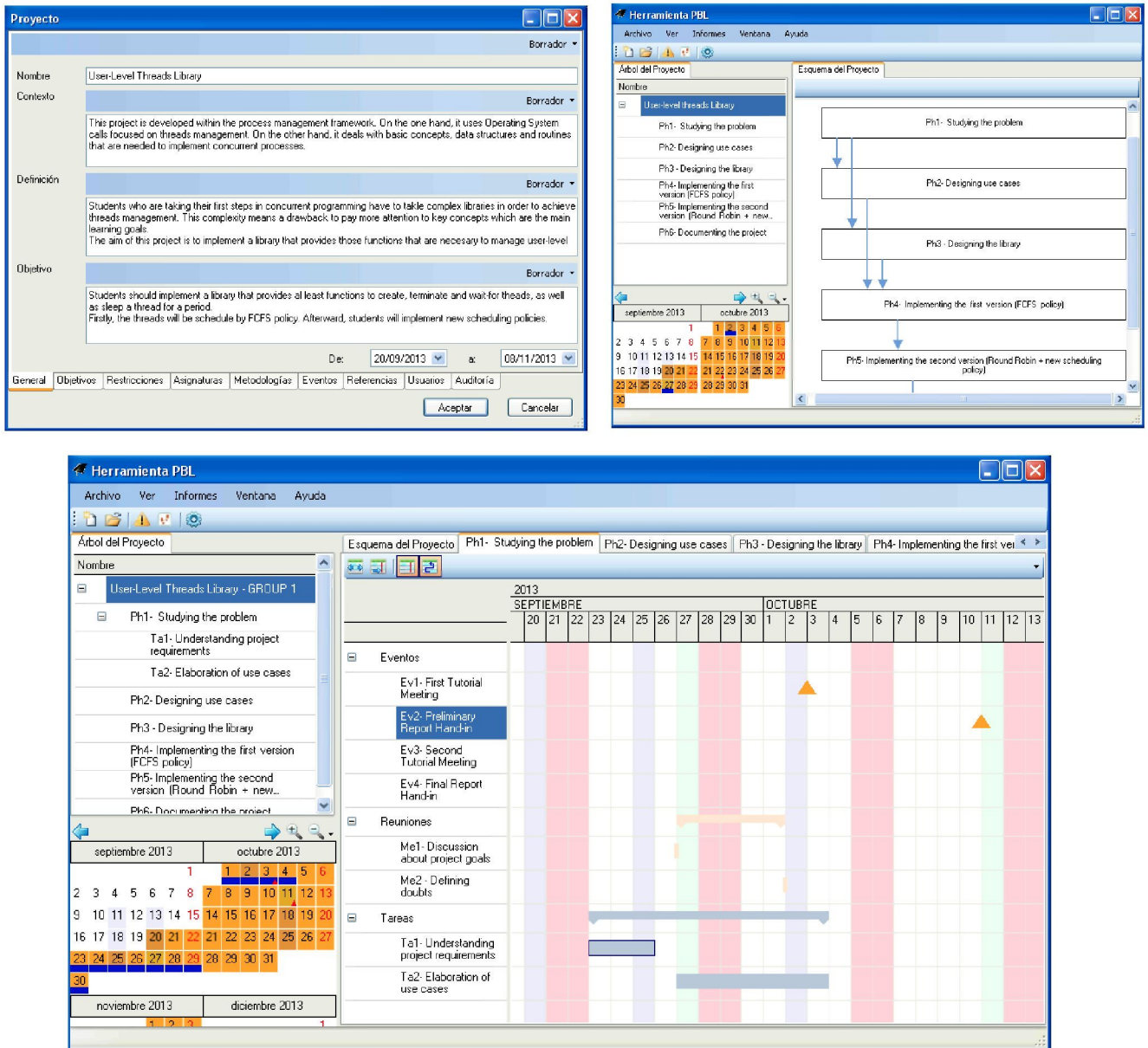


Figure 2: Examples of windows in PBLT.

Table 1 displays the results of the four questions selected for this study. Columns show the mean and standard deviation obtained for the last 6 years in the Operating Systems course. In the years 2014 and 2013 the method described in this article was used in order to organize the teaching-learning activities. Previous years implemented PBL activities without a specific design of motivation and support. In the year 2012 worse results were obtained. Teachers in charge of these course explained that the part of the course dedicated to theory was organized following Cooperative Learning methodology (in particular the jigsaw technique) and it was not well received by students. This fact could influence on the general opinion of students about the course. Then we have established three groupings, OS2014-13, OS2012 and OS2011-10-09 in order to analyse significant differences.

First exploratory analysis of data was carried out in each of the groups. This analysis includes the sample size, the minimum and maximum values, the mean, the variance, as well as

Kolmogorov-Smirnov and Shapiro-Wilk tests to check if each of the variables follow the normal distribution. Statistics of the three grouping can be observed in Table 2.

Table 1: UPM survey

	OS 2014 N=15	OS 2013 N=14	OS 2012 N=24	OS 2011 N=22	OS 2010 N=27	OS 2009 N=38
I7	5,07 (0,77)	5,14 (0,83)	4,25 (1,09)	4,77 (1,04)	4,60 (0,69)	4,55 (1,04)
I11	5,07(0,68)	5,36 (0,61)	3,58 (1,47)	4,33 (1,13)	4,70 (1,01)	5,08 (0,81)
I15	4,8 (1,17)	4,64 (0,61)	3,54 (0,96)	4,43 (0,95)	4,33 (1,05)	4,24 (0,91)
I16	4,73 (1,18)	4,79 (0,67)	3,65 (1,13)	4,29 (1,12)	4,44 (1,07)	4,27 (0,89)

Table 2: Statistics of groupings

Item	Group	N	Mean	Stand. Dev.	Stand. Error
I7	OS2014-13	29	5,10	,817	,152
	OS2012	24	4,25	1,113	,227
	OS2011-10-09	85	4,62	,963	,104
I11	OS2014-13	29	5,21	,675	,125
	OS2012	24	3,58	1,501	,306
	OS2011-10-09	86	4,78	1,011	,109
I15	OS2014-13	29	4,72	,960	,178
	OS2012	24	3,54	,977	,199
	OS2011-10-09	85	4,32	,978	,106
I16	OS2014-13	29	4,76	,988	,183
	OS2012	24	3,67	1,129	,231
	OS2011-10-09	85	4,33	1,016	,110

Therefore, we established the equality of means as null hypothesis and run t-Student test. Table 3 shows the results obtained for items I7, I11, I15 and I16 from the groups OS2014-13 and OS2012. In a similar way, Table 4 displays the results obtained from the groups OS2014-13 and OS2011-10-09. We can reject the null hypothesis (equality of means) for every item between groupings OS2014-13 and OS2011-10-09 with values  $t=3,215$ ,  $t=5,228$ ,  $t=4,428$  and  $t=3,755$  respectively, and p-value  $p < 0,05$  for I7 and  $p < 0,01$  for the remaining items. Nevertheless, as we have explained, this results can be influenced by the unsatisfactorily results of the cooperative learning sessions. On the other hand, if we compare groupings OS2014-13 and OS 2011-10-09, significant differences are obtained only in two items, I7 and I11, with p-value  $p=,018$  and  $p=,036$ . In item I15, although p-value is really close to 0,05 we cannot reject the null hypothesis. In item I16, p-value is equal to 0,05.

Therefore we can determine that, in the courses in which the method was applied, students have a better opinion about having “improved their starting level, regarding the competences established in the course” and considering that “the teacher assistance is effective to learn”.

Table 3: t-student for equality of means between OS2014-13 and OS2012

Item	t	gl	Sig.	Mean Difference	Stand. Error.	95% Confidence interval upper	95% Confidence interval lower
I7	3,215	51	,002	,853	,265	,321	1,386
I11	5,228	51	,000	1,624	,311	1,000	2,247
I15	4,428	51	,000	1,182	,267	,646	1,719
I16	3,755	51	,000	1,092	,291	,508	1,676

Table 4: t-student for equality of means between OS2014-13 and OS2011-10-09

Item	t	gl	Sig.	Mean Difference	Stand. Error	95% Confidence interval upper	95% Confidence interval lower
I7	2,402	112	,018	,480	,200	,084	,876
I11	2,123	113	,036	,428	,202	,028	,827
I15	1,941	112	,055	,406	,209	-,008	,821
I16	1,977	112	,050	,429	,217	-,001	,859

As far as the items I15 and I16 are concerned, I15-“The teacher achieves to arouse interest in the different topics studied during the learning activity”; I16-“The teacher facilitated my learning, and thanks to his/her help I improved my knowledge, skills or the way to face some topics”, although we cannot reject the equality of means in one of the groupings, differences are really close to be significant. These results could be influenced by the number of samples.

This semester, the course Programming Workshop is being taught during the spring semester in 2015. Besides organizing the course by following the method described in this paper we are developing an experiment which consists in two tests, Teamwork Questionnaire and Achievement Goal Questionnaire in order to analyze correlations between the method, teamwork competence and motivation of students. At the end of the term we will offer these results.

#### 4 Conclusions and future works

To sum up, we have described a method to design courses based on PBL. This method is based on three instructional design models and follows several learning theories. We have applied this method to two courses and it is being applied to a third course taught in spring semester. Results obtained from students’ opinion seem to be satisfactory, since students who followed those courses designed by using this method have a better opinion about their learning level and teacher assistance. Improvements in arousing students’ interest are really close to be significant. New experiments with a larger number of samples will help us to clarify this issue.

The method appears to be useful to help students to overcome the main difficulties when they are facing complex and ill-structured projects. Teachers pay more attention to analyze the support needed by students to overcome these difficulties and improve their motivation. At the end of the current semester we will analyze the results in Programming Workshop. Moreover, more experiments to analyze the effects of the method are needed.

We believe that nowadays it is important to develop some tools that facilitate the use of the method, engaging more instructors to use it. In this regard we are testing a first version of the tool PBLT and working on some improvements.

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