A Framework for Applying Problem-Based Learning to Computing Education

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***Abstract*—Ensuring satisfactory results by using problem-based learning in education in the Computing area is challenging. Faithfully maintaining the philosophy of PBL requires not only full compliance with its principles but also that its processes are managed efficiently. To facilitate the adoption of PBL, especially as to managing its processes, this article puts forward a framework based on Demig´s PDCA cycle. The framework highlights its ability to re-use artifacts and recommends models for the stages of planning, implementation, monitoring and corrective actions. Special attention is paid to the components that are essential to the framework: xPBL methodology, maturity models, such as PBL-Test and valuation models, and authentic assessment. Results on the applicability of the framework during an under-graduate modular Computing course are also presented.**

Keywords— PBL; Management processes; PBL Framework

I. INTRODUCTION

Traditional learning has been the target of constant questioning as to its viability with regard to the new needs of the processes of education and current modes of learning. Indeed, the traditional teaching method, because it is so culturally rooted in Education, keeps its focus on the verbalism of teaching and has little and/or no practical application. In this case, the disconnection between the knowledge taught and what is required in situations of adult life is pinpointed as being one of the main reflexes provided by this type of learning. Concept-oriented learning conditions the student to the memorization model, besides not favoring the development of inter-personal attitudes and skills.

In fact, learning should refer to the ability to apply what has been learned in new situations. Bringing students to the center of the learning process and involving them in problem-solving processes is the focus of the PBL methodology. Based on constructivist theories of learning, PBL regards the "problem" as the main learning procedure [1] and when applied on Computing courses, this ensures content and practices are aligned in a way that is consistent with professional reality. It happens that undergraduate courses in this area in Brazil keep the traditional format of the educational process and the vast majority of students feel unprepared to face the professional market of Information Technology (IT).

According to evidence identified [2], the main challenges associated with adopting PBL for computing courses are above all related to how it is applied. This paper emphasizes that lack of knowledge about the fundamentals of the methodology makes implementing and organizing the teaching and learning process unviable and difficult. There are differences between the methods (PBL vs. the traditional one) and understanding the principles that underpin PBL is indispensable for adopting it and making it effective in the process. This means that so that its adoption may lead to satisfactory results, adherence to the principles of the PBL methodology should be guaranteed, and this ensues when changes associated with the form of learning, the posture of the actors involved and the evaluation procedures are appropriate. Moreover, it is important to note that PBL is effectively recognized in the field of medical education since 1960. Many medical schools use this approach today. Despite this, it is clear that the methodology is applicable to different areas, including computing.

On considering the context of the need for changes to computer education associated with the characteristics and challenges of adopting PBL, this article presents a framework for applying PBL in this area. Although many definitions of a framework are presented in the literature, most converge to a similar concept, namely “a set of reusable objects targeting the application of a specific domain.” [3]. Research this indicate concerns to elements and isolated stages of the teaching and learning process. In [4], for example, reinforces the importance of Cognition situated to learning in PBL and its relation to the conception of the problems in a conceptual framework. However, just considering the design of ideal problems to a context does not guarantee the effectiveness of adopting PBL. Other variables must be considered and associated with the framework to actually explain their influence on the application results.

Therefore, the aim of the framework for applying PBL is to systematize the approach in methodological elements that make it easy to understand and adopt. The idea is to allow the reuse of the artifacts that make up the framework in order to facilitate managing the processes in PBL while undertaking real cases in Computing. The framework, which consists of well-defined steps, is based on Demig´s PDCA cycle by finding evidence

that cover the planning and implementation stages to the evolution of the process. As an essential component of the framework, a methodology xPBL, is presented. Besides exemplifying the elements of which it consists, so too are recommendations which are associated with applying management models and techniques to planning, in line with a real case. As to steps for monitoring and taking continuous actions that will enhance PBL, maturity models stand out and these include the PBL-Test and an evaluation model such as authentic assessment.

II. KEY REFERENCES METHODOLOGICAL

A. *xPBL Methodolgy*

One of the inherent characteristics of PBL is that it is strongly oriented to processes [5]. This means that adopting it can only be effective when it is ensured that the steps of the process are managed and conducted in alignment with each other. xPBL [6], besides being based on the principles of PBL, considers management methods and tools for the processes. Table 1 shows how PBL principles have been aligned to the five elements of xPBL.

TABLE I. ELEMENTS OF XPBL AND PBL PRINCIPLES

Key Elements of xPBL	**Principles PBL**
Problem	1. All learning activities are anchored on a task or a problem. 2. The learner should feel he/she owns the problem, and is responsible for his/her own learning. 3. The problem should be real. 6. The learning environment should stimulate and at the same time challenge the learner´s reasoning.
Environment	4. The task and the learning environment should reflect the reality of the professional market.
Content	5. The learner needs to own the process used so as to work out the solution to the problem. 7. The learner should be encouraged to test his/her ideas against alternative views and contexts.
Capital Human	9. The learning is collaborative and multidirectional.
Process	8. The learner should have the opportunity and support to reflect on the content learned and the learning process. 10. PBL is supported by planning processes and continuous monitoring.

In short, it is emphasized that the ten principles of PBL reinforce the methodology from the perspectives of teaching-learning process, the stance of those involved in this process and the form of monitoring and assessment. As for the elements of xPBL, that of the problem is the one that most relates to PBL principles, and this is mapped to principles 1, 2, 3 and 6. This element clarifies how learning takes place in PBL, and is always associated with problem-solving process that occur in a practical and collaborative way. In order to involve and motivate students, the problem needs to be real and its complexity similar to professional situations. The element of environment of xPBL reinforces the need to organize a learning environment that reflects real conditions of the labor market. Including real customers who ask for the projects, and taking into consideration the division of roles and responsibilities, which are associated with the duties that the students take on, support this definition. For the element of content, when this is mapped to principles 5 and 7, what are clarified are the ideas that, apart from the problem being associated with a conceptual base and one which must be acquired and applied, it is each student's responsibility together with his/her team to define and analyze strategies that can guide the process for solving the problem. Reflecting on the content involved should occur in a way that is aligned to the practices that take place to solve the problems. In this case, the learning takes place in a collaborative and multi-directional way (between students, students and teachers, students and tutors). Thus, the human capital element reinforces the idea of changes related to the student's stance, which should be one of being active and participative throughout the process. And finally, the element of processes being mapped to principle 10 reinforces the need for forms of monitoring and assessing this method that are appropriate. The idea is that the teacher can monitor the processes of finding solutions and conduct ongoing assessments throughout the process so as to identify what the students are finding difficult to learn in order to guide them when feedback is given.

B. *The PBL process*

By adapting what [7] proposed to the context of Computing Education, in which the learning cycle is usually highly interactive, the PBL process can be seen in Fig. 1 to comprise 10 steps.

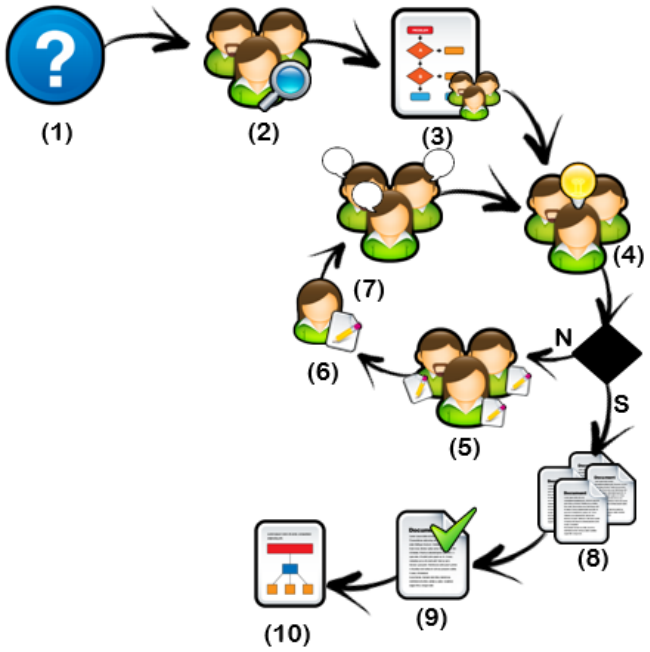

Fig. 1. The PBL process

The first activity of the process is the proposition of the problem (1), or simply the presentation of the problem. This activity reinforces the idea that the form of learning in xPBL occurs inversely, in the sense that problems should always precede whatsoever form of content/concept. The problems should be grounded, their conceptual basis being aspects

associated with the specification of each discipline. The students acquire knowledge during the process of their solving the problems, but if conducting how to solve them is to be effective, first of all, they need to understand what the problem is. Therefore, the activity defined as raising hypotheses (2) sets a pointer towards how the teams should seek an understanding of the causes of the problem, which were identified during the initial discussions. In other words, this activity prompts the students to analyze the problem in order to understand the domain for which they are trying to find a solution. In order to establish each member's responsibilities, teams should plan the group's work (3) so as to ensure the best way to head towards the process of solving the problem. This can arise by the students endeavoring to use their prior knowledge (4) and it may happen that the team´s knowledge is insufficient. In this case, the process branches into an alternative flow, which means that students need to conduct a survey of their learning needs (5). Learning issues are topics of potential relevance to the problem and are considered as points/ issues, an understanding of which the students are unaware or simply do not have. Clarifying such issues favors making decisions about defining the solutions proposed, besides guiding each member towards the need to engage on in-depth study (6). In this context, when raising learning issues, the team needs to define both its priorities and the responsibilities that define who will investigate such matters and when. Thus, learning becomes custom-made for each member, so each team member looks for information autonomously because their own tasks and strategies. It is during the group discussions and debates (7) that students should share information and lessons learned. The possibility of seeking information and sharing this with the others in every meeting becomes an attempt to develop viable alternatives for solving the problem. For the flow of activity in which it is considered that the students manage to define alternative solutions (8) without needing to make a survey of learning issues, this obviates the need to consider the application of knowledge and ideas when implementing the best solution (9) and in fact producing something concrete that can be presented to the assessment process (10).

C. *Authentic assessment*

The term "authentic assessment" was originally defined in [8]. In authentic assessment, students are involved in learning environments in which activities are focused on applying their knowledge, stimulating their thinking and critical insight into solving real problems and exercising different ways to solve them. Therefore, it is fully aligned to the PBL approach. The authors highlight the essential elements in an authentic assessment as to [8]: the reality of the context, problem and environment; the effective participation of students in the assessment process; the integration of evaluation into students' activities; and assessment based on clearly defined criteria and indicators. Although these elements highlight the principles to be considered in authentic assessment and which are aligned to the principles of PBL, they do not indicate how to apply this approach in a real learning environment, nor do they point out the assessment approaches to be used. Moreover, in [9] define authentic assessment strategies in the PBL context for three perspectives: Content, related to the knowledge acquired by students; Process, related to the ability to apply knowledge acquired in solving problems; Output, related to products and artifacts generated as a result. In [10] enhance this proposal and add two dimensions to the assessment process: Performance, which refers to a subjective analysis of the student's interpersonal characteristics, characteristics developed in the PBL approach; and Client Satisfaction, based on assessment criteria in the client's perspective of the solution.

D. *Maturity level in PBL*

In [11], the authors put forward a 10-question questionnaire, namely "PBL- Test": 1) Problem (s) at the core of the educational proposal; 2) Learner as the owner of the problem; 3) Authenticity of the problem or task; 4) Authenticity of the learning environment; 5) Driving the process for solving the problem; 6) Complexity of the problem or task; 7) Evaluation and analysis of how the problem was resolved; 8) Reflection on the content learned and the learning process; 9) Collaborative and multidirectional learning; 10) Continuous Assessment. Each participant's evaluation is defined by the sum of the points of the questionnaire, which, in the best case scenario, will have a score of 10. For simplicity, the result of the PBL-Test in a class of 20 students, for example, is calculated from the arithmetic mean of the scores resulting from the questionnaires of each student. Moreover, the PBL-Test associates the final score to PBL maturity levels: Level 0 or Insufficient (Overall average < 7); Level 1 or Initial (7 ≤ overall average < 8); Level 2 or Satisfactory (8 ≤ overall average < 9); Level 3 or Good (9 ≤ overall average < 10); Level 4 or Excellent (overall average = 10). Thus, a PBL approach that preserves its principles, therefore closer to its benefits, will have a maturity level between 2 and 4. Level 0 decharacterizes the PBL approach and level 1 indicates that hardly any principles are followed, so many improvements need to be made.

III. COMPONENTS OF THE PBL FRAMEWORK

This section describes in detail the elements that make up the framework for PBL applications in Computing education. Fig. 2 shows in diagrammatic form the relationship of the components to each stage of the PDCA cycle associated with the management techniques and models that can guide how the process and teaching and learning is carried out in this approach.

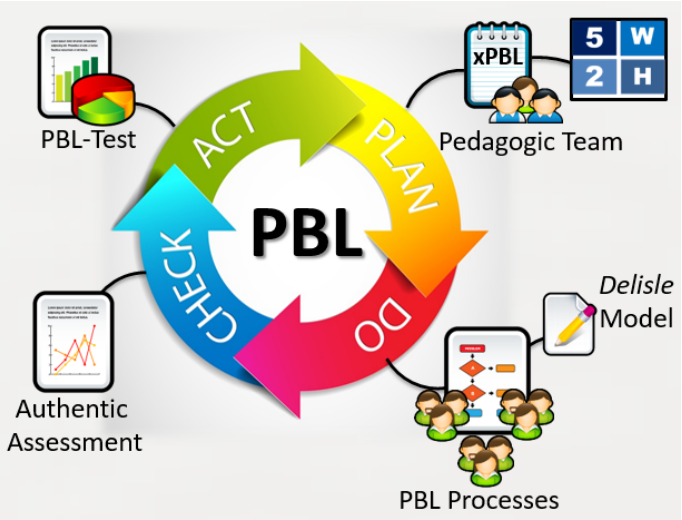

Fig. 2. Elements of the PBL Framework

A. Plan

Planning is a practice that is independent of teaching and learning methodology. For PBL, the act of planning becomes even more essential due to the flexibility and unpredictability associated with its form of practical learning. To ensure that the educational objectives are achieved by the students during the problem-solving process requires planning that is coherent with the different forms of this required by the methodology.

Due to the need to manage the processes, in xPBL, planning should be guided by management models and techniques that seek to ensure compliance with the elements that comprise it. In addition to Deming's PDCA cycle which enables the conduct of activities to be organized and guided with a view to continuously improving the process, the 5W2H technique is also recommended. The idea is to establish a general plan of action for the xPBL elements guided by questions related to the 5W (What, Who, Where, When and Why) and 2H (How and How much) questions.

Effective planning requires the activities of each element of the methodology to be broken down in order to specify what should be done (how, when and by whom), thereby establishing who is responsible for conducting the activity. As an example of applying the technique when associated with the Computing context, the section on applying the framework describes planning in detail as well as how all the instrumentation associated with the framework is used.

B. Do

Having defined the action plan for the xPBL elements using the 5W2H technique, the next step of the PDCA cycle to be considered is that of carrying it out. Effectively applying xPBL requires considering how to format the process and teaching and learning in PBL, as well as the principles which underpin it. To guide implementation in this approach, the PBL process, based on what [7] proposed, is recommended. This consists of ten well-defined activities.

In this process, the teacher's posture is also an aspect to be considered. Being a facilitator fits in with a PBL teacher knowing how to monitor /verify the evolution of the learning and how to guide the student. The framework indicates the Delisle problem-solving model [12] as a strategy to monitor the way that the teams think through the problem. It is believed that this type of model can be useful when aligned to carrying out the presentation activity of the problem because it systematizes the way in which students can solve the problem by defining steps such as "ideas, facts, hypotheses and action plan".

C. Check

This stage of the cycle favors verifying the results obtained by conducting the process of teaching and learning in xPBL. Checking the results in the educational process fits in with checking if the students reached the educational objectives set during this process. It is also known that the educational objectives should remain aligned with the forms of assessment. Due to the learning format, which is totally practical and functional, different strategies should be considered. An evaluation process in this approach should disassociate from subjective aspects and merely conceptual modalities of assessment, which is what happens in traditional methods.

In this context, xPBL methodology recommends an evaluation strategy aligned to the philosophy of PBL, defined as an authentic assessment under five perspectives, as shown in Fig. 3.

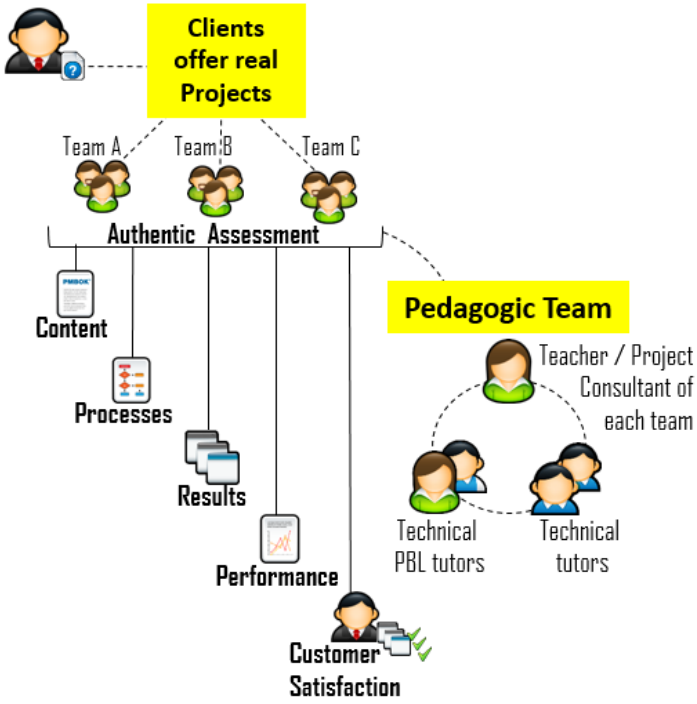

Fig. 3. Perspectives of Authentic Assessment

Each perspective is dealt with throughout the process and checks on a specific aspect. As for content, for example, a check is made that the foundations have been appropriated because

the team has been able to apply concepts to the problem-solving process. The process considers how the team solves problems, and defines strategies that suit the domain of the problem. The perspective of result considers the deliverables, which are the artifacts the students have produced and this is defined as a solution. As to performance, this is directly associated with the student's performance throughout the problem-solving process. The ideal for this perspective is to check whether the skills and attitudes have been acquired and/or been improved. Strategies recommended for this perspective may also be self-assessments and peer reviews, also known as 180º and 360º reviews. The main argument for adopting such strategies in xPBL reinforces the importance of students reflecting on their perceptions during the learning process, especially with regard to their difficulties. With regard to pair-assessments, a way is defined to monitor the team´s level of relationship and engagement during the problem-solving process and therefore to be able to intervene with respect to common situations and attitudes in traditional teaching practices such as an imbalance of dedication among the students. And finally, the customer satisfaction perspective slots the involvement of the real client into the process by checking their assessment of the team and the solution presented. In the context of xPBL, the client is a being engaged in the learning process who is responsible for requesting activities from the groups and at the same time for approving changes and/ or requirements of the solution being worked on.

D. Act

The last stage of the PDCA cycle corresponds to conducting corrective and/or preventive actions. For the context of the educational process in xPBL, such actions refer the importance of always complying with PBL principles in order to ensure the maturity of the methodology is at a high level. As important as planning and monitoring, the step of taking corrective actions befits evaluating the conduct of PBL with a view to evaluating possible deviations from the methodology and correcting them promptly.

In this context, the framework indicates a model to assess learning processes in the PBL, approach, namely PBL-Test [11]. The idea of the model is to check the maturity level of the process being conducted.

The present article argues that what is important is in the information identified apart from defining the level, such as a way to ensure the evolution and improvement of the process when it is in progress. Therefore, it is recommended that PBL-Test be applied as an activity in this stage of the cycle. By being considered as a management tool of the PBL teaching process, it is believed that the PBL-Test can contribute as to monitoring and defining actions for continuous improvements of the learning and teaching process.

IV. APPLYING OF THE PBL FRAMEWORK

This section describes the steps of the PDCA cycle when the framework was applied in the discipline of Project Planning and Management (PGP in Portuguese) of an Information Systems (IS) course.

A. Plan

The context of discipline is in the Project Management, the educational objective of which is to foster the training of students in good management practices by applying knowledge and skills while conducting real projects. In accordance with the systematization of the framework, the 5W2H technique guided the use of PBL- A in order to plan the discipline which was drawn up by a pedagogical team, comprising a teacher and four (technical and PBL) tutors, familiar with and experienced in applying PBL.

- *Problem*: Table 2 given as an example of applying the technique, sets out the element of problem, which was laid down for the discipline of PGP.

TABLE II. DEFINITIONS OF THE PGP PROBLEM IN ACCORDANCE WITH 5W2H

Questions posed by 5W2H	**Element of Problem**
What	Planning and management of an IS project using WEB 2.0 tools (SalesForce, SGC, Ning and other environments based on a high-level business component).
Why	To ensure the choice of the problem is compatible with the educational objectives and needs for skills training during the module.
Who	The Coordination Unit indicates the target group that the IS will benefit. Students choose the target audience, who will present opportunities for problems to be solved using IS.
Where	Indicated by the students, can assume a different target audience (women, students, children, the elderly, fans, etc.).
When	Class held after the first mock test.
How	By seeking the real client and problems to be solved; applying Delisle's model so as to define the project; describing the project by following the model presentation and; presenting the project chosen to the stakeholders.
How Much	Not applicable.
Artefacts	Template for describing the problem; reference for open and closed interviews and; presentation of the Delisle model.

In the context of the technique, the question "what" refers to the set of potential problems in which solutions were designed using the Web 2.0 tool or tools. "Why" justifies the need for the problems to be compatible with the educational goals of the discipline. The purpose of "Who" reinforces the need for the process to be similar to the real world, where the problems arise from real needs of customers who require and evaluate the results of a team. According to the planning, responsibility is attributed to the students (who?) for selecting the problem from among different requests (where?), early in the discipline (when?), in addition to developing a plan for solving the problem which is coherent and viable to the customer's context (how?). In addition to this technique of posing questions, the aspect of "artifacts" included in the table, enables the teaching staff to organize and assign activities to each member.

- *Environment*: The physical environment, represented by the classroom, had white boards, tables and caster-wheel chairs, which enabled the teams to be organized. In total there were 33 students, organized into six teams. To ensure a differentiated profile, how teams were formed was guided by rules that the teaching staff drew up as well as by applying the Myers-Briggs Type Indicator (MBTI). To facilitate communication a group was created on the social network Facebook, and on WhatsApp. The sharing of materials was guaranteed by cloud storage services such as Dropbox and Google Drive.

- *Content*: The main reference guide for the discipline is the PMBOK Guide, version 5, as it is one of the key references in Project Management. Foundations on agile approaches like SCRUM and KANBAN were also promoted by having lectures by experts with experience in the labor market. The entire content of the guide was revisited and associative dynamics were promoted. The course was planned to be conducted in three modules. The first module offered an overview of the PMBOK so as to introduce and contextualize prior concepts about the subject. The second and third modules focused on the phases of Initiating and Planning the life cycle of projects and the stages of implementation, control and closure of the project life cycle, respectively.

- *Human Capital*: This consisted of the university teacher and four tutors, each of whom had well-defined responsibilities. The presence of at least two tutors (one technical and the other PBL) respectively aimed to support students in all subjects of the discipline and to applying the methodology together with the teacher. The university teacher, who is the author of the xPBL methodology, is experienced in the IT field and holds PMI certification. She acted as a consultant of the projects developed by the students. Because these were real projects, each team had a real customer responsible for asking for and assessing the evolution of the Information System. Each team elected a Project Manager who was responsible for evolving the project.

- *Process:* The evaluation model adopted considers different perspectives, namely by assessing the students using authentic assessment, assessing the maturity of the PBL approach using PBL-Test and by final assessment of the discipline under criteria of planning and teaching performance.

B. Do

In order to adapt the students to the format of the discipline, in all classes they were involved in problem-solving processes which were planned in two stages. In the first, practices were undertaken as a strategy for finding the level of the class with regard to the concepts of the area. In the second, students were responsible for identifying and formalizing opportunities for identifying problems from real customers by using a form with questions that would be answered by giving details of the problem and the proposed solution. To guide them in this process, a dynamic activity associated with the Delisle problem-solving model was conducted [12].

To verify the suitability of the problems, all formulations were analyzed by teacher who used different criteria and scored them using a scale of from 1 to 4, for insufficient and excellent. Observations were communicated in feedback so as to guide the teams in the problem-solving process. Each team developed a project, of their own choice, of an agile management technique. A web tool was used to facilitate remote monitoring and in the Status Report (SR) meetings, the teams presented how their project was evolving. Real customers took part in these meetings either in person or by web conference.

C. Check

As a model for assessing students, authentic assessment was applied while considering the perspectives of Content, Process, Results, Performance and Customer satisfaction. Details of these perspectives are described below.

- *Content*: Related to an individual assessment, this perspective was checked using conceptual objective evidence of the Project Management area, based on PMI (Project Management Institute) standards. Among 20 to 25 questions, the evidence was organized as (1) overview of the PMPOK, (2) phases of Start and Planning of the life cycle of projects and (3) phases of Implementation, Control and Closure of the project life cycle. From the results obtained, the teacher formulated strategies to minimize the difficulties, especially to reinforce the concepts that the students barley adhered to.

- *Process*: Related to a collective assessment, the process perspective was checked, based on the teacher and technical tutor monitoring the evolution of projects and they associated this with the Kickoff and Status Report meetings. The teams were evaluated in accordance with presentations that guided the answers to questions about the purpose and planning of the project, besides what was done, strengths and points for improvement. Criteria such as (1) Clarity of presentation; (2) Mastery of the presentation; (3) Completeness when considering questions and (4) Understanding of Planning were rated in accordance with a scale of from 1 to 5 where "1 - Insufficient"; 2 – “Satisfactory"; "3 - Good"; "4 - Very Good; "5 - Excellent".
- *Results:* This perspective is also related to a collective assessment, the objective of which was to verify the results of each project team when considering the presentations at monitoring meetings. As evaluation criteria, the teacher and technical tutor considered aspects such as (1) Overview of the project; (2)

Planning of Activities; (3) Strengths and (5) Points for improvement. The same scale as the one used in the perspective of process was adopted in this perspective.

- *Performance*: In this perspective, competencies were checked that the students must acquire and/or improve in the resolution process. During the process of resolving the problem, it was necessary to plan activities as well as to assume responsibilities so that they could be completed. Group decisions should be discussed, analyzed and evaluated according to the context into which the problem and/or solution would fit. In this context, the skills considered and organized into a questionnaire were to do with self-initiative, commitment, collaboration, innovation, communication, learning, planning and evaluation. Applied under the formats of self-assessment and pair-wise assessment, each competency was analyzed using a scale with values such as (1) "did not meet expectations"; (2) "partially met them"; (3) "met them"; (4) "met them very well"; (5) "exceeded expectations". The expectation associated with these forms of assessment matches the possibilities. The students in addition to conducting critical self-assessment of their own performance, evaluate their peers in a way that fits what is true to what happened in real practice. To avoid any inconsistencies in the responses, each member of the teams was assessed by their peers anonymously. It is important to stress that a radar graph was generated for each student in this perspective.

- *Customer Satisfaction*: Finally, this perspective became indispensable to the evaluation process of the discipline, since each client was benefited with a solution in accordance with their needs. Considering the customers' opinions when the project is being monitored maintains an assessment that fits in with verifying the criteria about the team and the very solution presented. Criteria such as open-endedness in the interviews, understanding of the problems, clarity of the presentation, quality of the solutions proposed and planning level were included. The same scale as the one used in the process perspective was adopted in this assessment.

D. Act

The application of the model for assessing maturity, PBL-Test, reinforces the need to ensure compliance with PBL principles during the whole process of teaching and learning. For the context of the discipline, more than 80% of students answered the questionnaire and a level 2 – satisfactory result was obtained which indicates that the process evaluated adheres significantly to PBL principles.

V. Conclusions and Implications

Conducting PBL requires care and rigor as to its philosophy, both with regard to adhering to the principles and to the management of the process. In this context, this article draws special attention to the framework for applying PBL in the Computing area with artifacts that facilitate comprehension when PBL is adopted. The idea is to foster adoption by recommending management techniques and models aligned to methodological artifacts that may guide how PBL processes are implemented.

From considerations about a case study, it was possible to show how this PBL framework could be applied in real educational practices, what elements should be planning and monitoring in an educational project (Problem, Environment, Human Capital, Content and Processes), having as facilitator the xPBL methodology, an assessment model for students evaluation based on different aspects (Content, Process, Output, Performance and Client Satisfaction) and an instrument to evaluate the guaranty of the PBL principles.

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