PBL-SEE: An Authentic Assessment Model for PBL-Based Software Engineering Education

Simone C. dos Santos

***Abstract*—The problem-based learning (PBL) approach has been successfully applied to teaching software engineering thanks to its principles of group work, learning by solving real problems, and learning environments that match the market realities. However, the lack of well-defined methodologies and processes for implementing the PBL approach represents a major challenge. The approach requires great flexibility and dynamism from all involved, whether in mapping content, in teacher performance, or laying out the process of how learners should go about solving problems. This paper suggests that management processes can help in implementing PBL throughout its life cycle (planning, implementation, monitoring, and enhancement), and proposes an assessment model called *PBL-SEE* for use in software engineering education (SEE). Two examples of its use are provided. The results show how the model can be applied and how the resulting information can be used to make the PBL initiatives "authentic," in that they bring the reality of the labor market to the learning environment, while keeping to PBL principles.**

***Index Terms*—Bloom's taxonomy, case study, problem-based learning (PBL), problem solving, professional skills, student assessment, teaching evaluations.**

I. Introduction

THE STUDY and practice of software engineering is influenced both by its roots in computer science and by engineering disciplines with their focus on professional skills. According to [1], certain broad characteristics are expected of computing graduates that go beyond technical knowledge; in particular, they must have project experience and problem-solving skills and an appreciation of the interplay between theory and practice. From an engineering perspective, the curriculum in [2] reinforces the importance of problem-solving skills in the statement, "*Engineers proceed by making a series of decisions, carefully evaluating options, and choosing an approach at each decision point that is appropriate for the current task in the current context.*" However, to develop such competences, applied learning is necessary, as distinct from traditional lecture-oriented classes that focus on delivering subject-matter knowledge and have little time for practical activities. Such classes are generally very different from real-life situations. In a real environment, the client has a problem that requires a software solution within time and cost constraints; that problem can be poorly structured and subject to change, and often has aspects that the client does not understand. To respond, software engineers often work in teams, communicating and sharing their knowledge with colleagues, using tools and adaptive processes, and being oriented to common goals. In traditional learning, students tend to work individually, are often forbidden to cooperate and share their knowledge with peers (for evaluation purposes), and are encouraged to simply memorize knowledge and then reproduce it in summative tests. When they are given a project-based practical, its learning complexity is minimized by carefully structuring the projects and providing stable conditions within the boundaries of the discipline being taught. A learning environment, though, should not only be practical but also true to market reality. Problem-based learning (PBL) is an appropriate way of doing this, being focused on putting students at the center of the learning process and involving them in real situations. This method, based on constructivist theories of learning [3], has been used in education where students work in teams to solve problems, fostering the development of skills such as self-initiative, cooperation, and learning to take a critical viewpoint.

According to [3], a systematic literature review that analyzed 52 studies of PBL applied to computing education, the adoption of PBL is not an easy task. The main challenges are related to the way in which it is applied. In practice, if the principles of PBL are to be adhered to, there must be a high investment in managing it, requiring additional time, and additional people taking certain roles and overseeing certain processes; as a result, these principles are not always closely followed. Managing processes, such as assessment processes, is indispensable to obtaining positive results from PBL.

Some studies have shown effective results. Following an experiment in which teachers were trained in PBL, Tuohi [5] discussed some important points in the definition of the evaluation process in PBL, highlighting the best approach (formative or summative), the need to define who assesses what, the best assessment tools (oral or written), and the type of indicators to be used, emphasizing the importance of having all parties participate in the evaluation process, and of continuous feedback throughout the process. Yin [6] highlighted the importance of formative assessments in the PBL approach, both in the assessment of student groups and of in individuals. Additionally, Elizondo-Montemayor [7] highlighted the need for alignment between the educational objectives (EOs) and the evaluation process: "*Assessment of PBL needs to focus on the objectives*

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The author is with the Centro de Informática, Universidade Federal de Pernambuco, Recife 50740-560, Brazil (e-mail: scs@cin.ufpe.br).

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that PBL fosters in conjunction with the educational course objectives." These studies discuss issues relevant to the PBL assessment process, but none proposes a model that supports its implementation.

This paper, prompted by this need, describes an assessment model for the PBL approach in software engineering education (SEE), called PBL-SEE. The underpinning for PBL-SEE comes from the models of evaluation processes used by software industry professionals and theory-based academic assessment models. The proposed evaluation model has three levels: 1) student assessment; 2) PBL evaluation; and 3) teaching assessment.

One of the main tenets for level 1 is the concept of "authentic assessment" presented by Herrington and Herrington [8], who emphasized that the context and the problem need to be real, to provide conditions for assessing student performance, with intense student collaboration and participation. Additionally, the assessment needs to be integrated with students' activities, including multiple and well-defined performance indicators. In the software industry itself, this learning environment can be created through "software factories," defined as structured and integrated units of development, with clear roles and responsibilities, supported by well-defined tools and processes, as described in [9]. Level 2 considers the results presented in [10], focusing on assessing the maturity of the PBL approach. Finally, level 3 focuses on teachers' performance and their planning of the teaching program. Section IV presents a discussion of the application of PBL-SEE in two real cases, in both professional and academic contexts.

II. Theoretical and Methodological Frameworks

Four major theoretical and methodological bases are used in this paper.

The first deals with the management of the teaching and learning cycle. Dos Santos *et al.* [11] showed that PBL can be adopted effectively when guided by a well-defined process of planning, implementation, monitoring, and evaluation, so as to implement continuous improvements. These process steps refer to plan, do, check, and act (PDCA), a methodology whose basic function is to aid the diagnosis, analysis, and resolution of organizational problems. The PDCA cycle is divided into four well-defined steps:

1) *Plan* consists of establishing the objectives, goals, and processes to be controlled so as to achieve the desired results.
2) *Do* consists of performing the planned activities, implementing the processes and collecting data for evaluation.
3) *Check* consists of monitoring and periodically evaluating the processes and results obtained as compliance with the set goals and objectives.
4) *Action* consists of acting according to the evaluation, taking corrective action to avoid possible failures and to improve the quality, efficiency, and effectiveness of the processes involved.

A second theoretical basis advocates the use of classification schemes to facilitate the definition of EOs, more specifically, the Revised Bloom's Taxonomy by Anderson and Krathwohl [12]. They altered the cognitive domain of Bloom's Taxonomy (*Knowledge*, *Understanding*, *Application*, *Analysis*, *Synthesis,* and *Evaluation),* calling it the Revised Bloom's Taxonomy (RBT), keeping the six levels in verbs:

1) *to remember* or reproduce ideas (verbs: recognizing and playing);
2) *to understand*, explaining an idea/concept in one's own words (verbs: interpreting and summarizing);
3) *to apply* knowledge to a new and concrete situation (verbs: implementing and carrying out);
4) *to analyze*, dividing information into parts, being able to understand the interrelationship between them (verbs: organizing and differentiating);
5) *to evaluate* based on criteria, standards, and norms (verbs: checking and criticizing);
6) *to create* a new vision or solution based on the knowledge and skills previously acquired (verbs: producing and planning).

A third basis is a PBL methodology presented in [13]. Given that the model proposed in this paper is focused on computing education, specifically, software engineering, "xPBL," a PBL methodology created for that field was used. Its purpose is to align methods and tools used to manage the PBL approach, so that PBL principles can be guaranteed when it is adopted to teach computing. To guarantee PBL principles beyond their educational goals, xPBL is based on five elements:

1) *Problem*, selecting actual problems, whose complexity is treated as a significant aspect;
2) *Environment*, creating an actual real-world work environment;
3) *Human Capital*, having professional experts as teachers and tutors, with the students as actors and real clients involved in the teaching process;
4) *Content*, compiling an innovative syllabus whose content closely reflects actual problems;
5) *Process*, implementing an authentic assessment process based on the teams' results and the students' knowledge, and, from a technical and market perspective, a tight control enforced by monitors.

This last basis refers to the term "authentic assessment," which was originally defined by Herrington and Herrington [8]. Tai and Yuen [14] emphasized that "*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.*" Although this model is fully aligned to the PBL approach, it gives no indication of how to apply this approach in a real learning environment, nor suggests the assessment approaches to be used. Tai and Yuen [14] defined authentic assessment strategies in the PBL context from three perspectives: 1) *Content*, related to the knowledge acquired by students; 2) *Process*, related to the ability to apply that knowledge to solve problems; and 3) *Output*, related to the products and artifacts generated as a result. Dos Santos and Soares [15] enhanced this proposal and added

TABLE I
ASSOCIATION BETWEEN THE BASES OF THE MODEL

xPBL Elements	Assessment Perspectives	Educational Objectives (EO)	EO Id
Problem	Output	Apply	EO-2
Environment/ Context	Client Satisfaction	Evaluate (external view)	EO-3
Human Capital	Performance	Evaluate (internal view)	EO-4
Content	Content	Remember/ Understand	EO-1
Process	Process	Analyze/ Create	EO-5

two dimensions to the assessment process: 1) *Performance*, which refers to a subjective analysis of the student's interpersonal characteristics, developed in the PBL approach; and 2) *Client Satisfaction*, based on assessment criteria in the client's perspective of the solution.

From this, Table I shows an association between these three elements: 1) xPBL methodology; 2) authentic assessment strategies and procedures for teaching software engineering; and 3) the development of cognitive processes according to the RBT. In analyzing Table I, the "problem" element of PBL recommends that its use in the learning process be real and of relevant complexity so that the solutions developed by the learner are also relevant. At this point, the focus on the solution to a problem indicates a greater emphasis on the level of application of knowledge, guided by the associated verbs "implement" and "carry out" of the RBT. From the point of view of the assessment procedure, this will be related to the output element, which represents the result generated by the solution of the problem.

As for the second element, xPBL highlights the need for a learning environment that reflects the context and real conditions of the work environment. This element reinforces the need to bring the external environment (outside the academic environment) into the learning environment. To do this, actors from that external environment are brought into the evaluation procedure, thus assessing the satisfaction of the person needing the solution, the real client. The third xPBL element deals with the roles involved in the learning process, with emphasis on the central members in the proposed solutions, the learners. At this point, the assessment process is focused on assessing the interpersonal characteristics associated with the level of knowledge of the learner and of his/her team collaborators. Evaluation of knowledge and understanding of concepts, fundamentals, methods and techniques, and so forth, is made in the fourth element of xPBL, and examines the content that will support problem solving. Finally, the last element reinforces the need for a learner assessment process compatible with the problem-solving process, evaluating the combination of competences used to analyze how the problem will be solved, to analyze alternative solutions and to adapt the resolution process to the problem situation.

III. PBL-SEE MODEL

The objective of the PBL-SEE model is to indicate assessment strategies that guarantee the effectiveness of the PBL approach throughout its management cycle (in accordance with Deming's PDCA cycle). Since the first step is to define EOs, the PBL-SEE model is defined as a guideline for the development of competences based on the association shown in Table I.

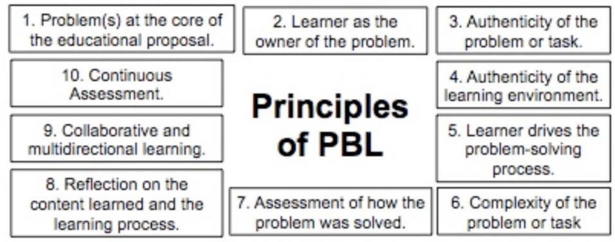

Fig. 1. Ten principles of PBL.

(EO-1) *To know and understand concepts and fundamentals applicable to problem solving.*
(EO-2) *To apply acquired knowledge to solve problems.*
(EO-3) *To evaluate proposed solutions against the actual client's criteria.*
(EO-4) *To assess one's own interpersonal skills and those of one's team.*
(EO-5) *To analyze and create (or adapt) resolution processes that best apply to the problem situation.*

Note that the EOs were written with Bloom's verbs, associated with the aspects of authentic assessment aligned to the elements of xPBL.

Based on these objectives, the authentic assessment elements applied to the teaching of software engineering proposed in [15] are taken as a model for "*student assessment*," within the five dimensions of assessment: 1) content; 2) process; 3) output; 4) performance; and 5) client satisfaction. In addition, two new levels of assessment are considered: 1) "*PBL evaluation*," and 2) "*teaching assessment*."

For PBL evaluation, dos Santos *et al.* [10] put forward a ten-question test, "PBL-test," based on ten PBL principles, as shown in Fig. 1.

Each participant's evaluation is defined by their score on the test, for which the maximum score is 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 each student's score on the test. Moreover, the PBL-test associates the final score to PBL maturity levels: level 0 or insufficient (overall average < 7); level 1 or initial ($7 \leq$ overall average < 8); level 2 or satisfactory ($8 \leq$ overall average < 9); level 3 or good ($9 \leq$ overall average < 10); level 4 or excellent (overall average $= 10$). Thus, a PBL approach embodying the method's principles, and its benefits, will have a maturity level between 2 and 4. Level 0 is not characteristic of the PBL approach, and level 1 indicates that few of the principles are followed and many improvements need to be made.

At the teaching assessment level, the objective is to assess two aspects: 1) the teacher's performance, and 2) the planning of the educational or training unit. The teacher's performance assessment considers characteristics of the teacher's professional and interpersonal competences, such as oral and written communication ability, manner and ethics when dealing with students, and stimulating students to solve problems.

Further aspects are management skills and business vision, such as planning of teaching, setting challenging tasks, and the teacher's professional experience. This aspect is defined with respect to the profile of an ICT expert whose competences are as demanded by the labor market, as set out in the ICT profession body of knowledge [16]. The second aspect refers to the planning of the teaching process and is associated with setting EOs, the transparency of these goals and their achievement throughout the course. Finally, a subjective evaluation is made of the student's perception of the outcome of the learning process for his/her CV and professional training.

IV. Cases Studies

The PBL-SEE model has been applied since 2007 in various courses with a professional emphasis, such as ten years of a Software Engineering Master's program [11], a professional training course in software testing [17], and a software residency for developing a mobile platform [18]. In this section, two case studies are given: 1) the software residency (SR) study, and 2) the project management (PM) study.

In the SR study [15], the goal was to train software professionals in the skills needed to work in companies of telecom sector infrastructure products. The program consisted of a group of 18 residents, organized into two groups of nine residents as software factories: 1) group A, focusing on the development of embedded software for the products; and 2) group B, which focused on software development for network management in Java. The human capital comprised a coordinator, 11 teachers, two technical tutors, and two real clients, one for each team.

In the PM study [19], xPBL methodology was applied to the project management course on an undergraduate Information Systems Degree Program. The educational goal was to train students in good practices in systems project management. The environment consisted of 33 students, divided into six teams, organized in six software factories. The main guidelines for content were the PMBOK Guide v5 and agile management approaches for software projects (Scrum and Kanban). The human capital comprised a teacher, two technical tutors, two PBL tutors, six teams with five/six students, and six real clients, one for each team, mostly freelance professionals (entrepreneurs).

A. Plan and Do

For the SR case study, the student assessment was planned for five months of training, with the following assessments: 1) eight on content; 2) four on process; 3) four on output; 4) two on performance; and 5) two on client satisfaction. In the period when the courses were given (the first four months), content assessments were made in each course. Therefore, there were eight content assessments for teams A and B, considering a group of five courses common to both teams and three courses specific to each group with a total of 11 short courses. These evaluations were carried out by the course teacher, with emphasis on the first EO of the PBL-SEE (EO-1). For objectives EO-2 and EO-3, and considering that the teams used an agile management approach in the projects

Students	Network	APM	Datacom	Linux	CM	Java	Java 2	Test	Avarage
B1	4444444444444444		333333333	222222	3333	11111	222222	3333333333333333	
B2	4444444444444444		333333333	222222	3333	1111111111111		3333333333333333	
B3	4444444444444444444444444			222222	4444	3333333333333333333			444444444
B4	4444444444444444444444444			222222	333333333333333333333333				444444444
B5	4444444444444444444444444			222222	3333	22222	3333333333333		333333333
B6	4444444444444444		3333333333333333333333333333333333333333						444444444
B7	444444444	333333333333333		11111111111		22222	111111	333333	222222222
B8	44444444444444444444444444444444				3333	44444	333333333333		444444444
B9	444444444	333333333333333333333333333				22222	111111	222222	333333333

0- Unsatisfactory; 1 – Satisfactory; 2 - Good; 3 - Very good; 4 – Excellent

Fig. 2. Process and result assessment data for team B.

focusing on a larger number of short iterations (e.g., Scrum), the process and output assessments were applied to each iteration such that the teams were evaluated at the end of each of them. These evaluations were conducted by the technical tutors and the project manager. Moreover, two performance assessments were planned, one at the beginning of the project and one before the month dedicated to the practicals in order to correct possible interpersonal conflicts, as guided by OE-4. However, only one assessment was carried out because of time constraints. Finally, for objective EO-5, there were two assessments of the client aspect, one conducted midway through the program and the other at the end. Unfortunately, the PBL-Test was not administered because it was still being prepared when the program was run. The assessments of the level of teaching assessment were made at the end of each course.

In the PM case study, the student assessment was made throughout the course (four months), with the following assessments distributed in three modules: three on content; four on process; four on output; two on performance; and four on client satisfaction. For the first module, understanding the concepts and basics of project management was required (EO-1), and only one content assessment was planned in the simulated format (objective tests of about 25 issues), a format used in the real Project Management Institute certification tests. During the second and third modules, two content assessments were planned (for OE-1) using the same simulated format, and four groups of assessments of process, output and client satisfaction, conducted during the follow-up or status report meetings (in accordance with the objectives EO-2, EO-3, and EO-5). The assessments under the aspect of performance (EO-4) were applied at two points in the course: after the first and third status report meetings. The PBL-test was applied after the second status report meeting, with focus on PBL principles. Teaching assessment evaluations were planned at the end of the course, such as the SR Study.

B. Check and Act

In the SR case study, simple content aspect graphics were built that assigned colors (here shown with numbers) to the value scale for to this aspect (0—unsatisfactory; 1—satisfactory; 2—good; 3—very good; 4—excellent) as shown in Fig. 2, with reference to team B.

This graph allowed the course project manager to monitor the evolution of the two teams, with focus on EO-1, and to identify subjects giving students greatest difficulty, thus providing assistance such as extra classes and technical tutors, when necessary.

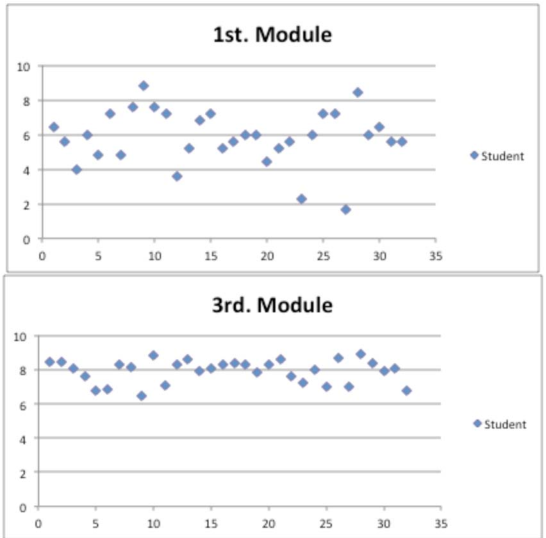

Fig. 3. Individual student performance in two modules of the PM case study (*x*-axis: individual students, and *y*-axis: score).

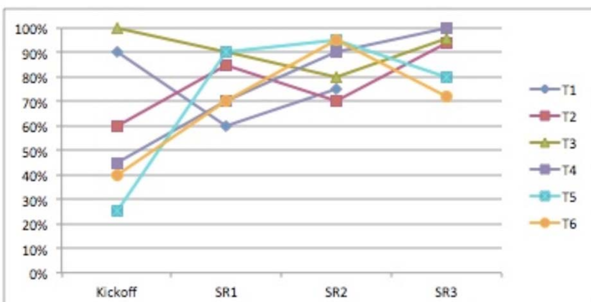

Fig. 4. Evolution of process aspect in the PM case study. SR = status report meeting, and T = team.

In the PM case study, scatter plots were generated at the end of each of the three modules, Fig. 3, thus allowing an analysis of the groups by individual performance, this being an undergraduate degree, not a professional training course qualification offering hiring possibilities, as in the SR case. An improvement is seen comparing the two graphs, considering that the first was focused on the content aspect (from arithmetic average of individual tests), and the second was focused on the five aspects of authentic assessment (from the arithmetic average of all evaluations).

For the process, results, and client satisfaction aspects, data were collected for each team from evaluation spreadsheets (each one with respective criteria) shared with teachers, tutors, and all students on the courses on a cloud platform. For example, some criteria used in the evaluation under the process aspect were "clarity of the process," "completeness of presentation," and "planning strategy." Once again, after the status meetings, graphs were generated showing the teams' evolution, with a focus in the objectives EO-2, EO-3, and EO-5. One such graph, generated for the process aspect for the PM course, Fig. 4, shows the teams' improvement throughout the case study, from a mainly low initial performance. At each evaluation, all the teams (T1–T6) were given feedback and recommendations.

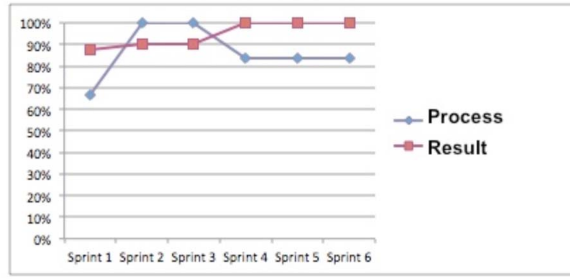

Fig. 5. Process and result assessments for one team after each sprint in the SR case study.

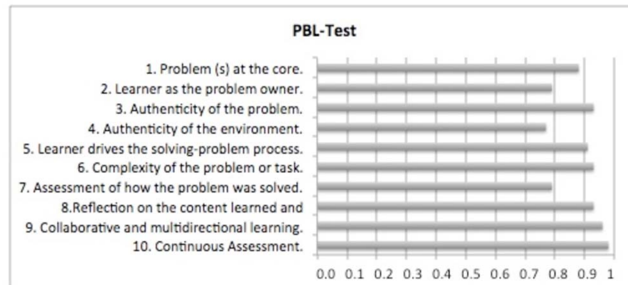

Fig. 6. Results of the PBL-test for each principle.

In the SR case study, the teams had to use a development process compatible with continuous delivery of products (output). This was assessed by using graphics that related EO-2 (applying acquired knowledge to solve problems) to EO-5 (evaluating proposed solutions against the actual client's criteria). The objectives of a professional education can thus be made consistent with the needs of the client company (EO-3). Fig. 5 shows a graph plotting the process and result aspect evaluations generated after each project sprint for one of the teams. Students can use this feedback to decide to, for example, simplify parts of the process, to focus on delivering a quality *product* rather than a quality *process*. This kind of decision falls within the project manager's role.

Client satisfaction assessments were made through a spreadsheet sent to the client at two points during the study. This spreadsheet listed criteria, their descriptions, and gave fields to assign a value for each criterion. Team A achieved an excellent rating in this aspect for both assessments. In their first assessment, team B was rated as needing improvement in the two areas of product quality and innovation. The team then worked on these points, with adjustments in the development process, and achieved a better performance in the second assessment. Feedback from real clients is very important, in accordance with EO-5, and has a direct impact on the authenticity of the learning environment and the problem to be solved. Without involving those who are experiencing the problem, it is very difficult to achieve good solutions.

To assess performance, students, tutors, and the project manager completed online research tool forms, similar to the graph of Fig. 1, that had columns for each evaluation criterion (initiative, commitment, collaboration, leadership, etc.) where a value was entered according to that particular value scale. Sophisticated reports could then be obtained for each student,

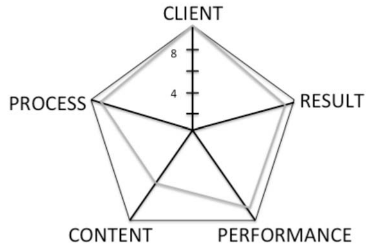

Fig. 7. Student assessment under the five aspects.

showing their own assessment, and that of their teammates, in a consolidated graphic for each assessment criterion, along with subjective comments. After these assessments, face-to-face meetings are often held to discuss any team conflicts, for example, in personal relationships or in common interests. Students' interpersonal skills are thus emphasized, in accordance with EO-4.

In the PM case study, the PBL-Test gave an overall average of 8.8 (level 2 or Satisfactory), Fig. 6. Note that the maximum value for each principle is 1, thus the maximum value for PBL-Test is 10.

These results show that most of the PBL principles were met, but also point out potential for improvement, such as the unsuitability of the traditional classrooms available in the academic environment. Should departures from the principles of PBL be identified that can be tackled during the course, the PBL-test should be used more frequently to assess improvement.

To assess the teacher in the SR case study, evaluations were made at the end of each of the 11 short courses to see if content changes were necessary, or if other actions were required. Most of the results were "excellent" and "very good" and showed a high degree of satisfaction with the teachers and teaching approach, except in one course at the beginning of the program, not uncommon in an adjustment period. In this case, a new teacher was hired and the course repeated, with a significant improvement in student performance.

Finally, exploring specific levels of the PBL-SEE, such as student assessment, graphics can be designed to provide consolidated student performance information. The 5-D graphic of Fig. 7, for example, shows the performance of a team on the PM course, for the five dimensions. This chart could be generated for each student on a course and used to provide feedback on overall performance.

Using information technology, including artificial intelligence and statistical techniques, to process information allows the PBL-SEE model to make highly sophisticated and comprehensive analyses. If consistent data are collected, the decision support reports can be generated that allow self-regulation and the implementation of improvements.

V. Conclusion

The PBL-SEE evaluation model described here supports the PBL approach to the teaching and learning process with a management cycle that offers the pedagogical coordinator a full view of the planning, implementation, monitoring, and continuous improvement stages. The concern with the managerial aspects of the proposed model is relevant because the PBL literature is more descriptive than prescriptive; that is, clear normative instructions are lacking on how to implement and, subsequently, check that an educational proposal under the PBL approach has met its objectives. The assessment strategies proposed in the PBL-SEE model seek to ensure the effectiveness of the PBL approach, taking into account the planning of the educational unit, teacher's performance (teaching assessment), the degree of maturity of the PBL approach (PBL evaluation), and the learner's experience within the five evaluation dimensions: 1) content; 2) process; 3) results; 4) performance; and 5) client satisfaction (student assessment). Based on the case studies, the PBL-SEE model has demonstrated its positive contribution in supporting the teaching of software engineering with PBL, whether in the academic or professional context, in a learning environment created by setting up practical software factories. Its characteristics of continuous evaluation and feedback guide students in their studies so as to reach their educational goals.

Finally, despite the complexities of real software development scenarios, it is believed that the application of this assessment model is suitable for any project environment aimed at solving problems in which groups of people collaborate and cooperate with clear goals to serve and meet the needs of real clients.

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Simone C. dos Santos received the Project Management Professional Certification from the Project Management Institute, Newtown Square, PA, USA, in 2006.

She is a Senior Lecturer with the Informatics Center, Federal University of Pernambuco, Recife, Brazil. She is also the Head of the Innovative Educational Experience in Technology Research Group, which researches the area of education and technology, with an emphasis on the problem-based learning approach. As a specialist in the area of process management, she engages in research and consultancy activities in the areas of educational methodologies, project management, and business process management.