Student Assessment in PBL-Based Teaching Computing: Proposals and Results

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***Abstract*—This Research Full Paper presents an overview of student assessment proposals for Problem-Based Learning (PBL) in Computing Education. Computing teaching has many challenges, as it requires different skills from students, often subjective and difficult to assess. In fact, technical knowledge alone is not enough to fully understand what is being taught, but the interpretive and logical skills to deal with practical problems and non-technical skills such as group work, creativity, critical vision, ability to cooperate and communicate. Active learning methodologies as Problem-Based Learning (PBL) have been used to dealing with such challenges, broadly developing technical and non-techniques skills in students. However, despite the benefits of PBL, the student assessment process is one of the points that present its own adversities and, therefore, an aspect that deserves greater attention. To better understand the nuances of this process and how it can contributes to the teaching and learning process based on PBL, this study aimed to investigate primary studies in the last two decades, seeking answers to the following research questions: RQ1) What assessment models are being used?; RQ2) Which aspects are evaluated?; RQ3) What criteria and media have been defined?; RQ4) Who gets involved in the assessment process?; RQ5) What is the ideal frequency to conduct the evaluations?; RQ6) What can these models reveal? As a research method, this study used the Systematic Literature Review method proposed by Kitchenham. As main conclusions, it was possible to identify that: generally, computing education based on PBL occurs at the undergraduate level, having as main educational objective the teaching of technical content; in practice, the need for a diverse teaching team is not reflected, the traditional student-teacher remains; to evaluate students, it is necessary to consider several aspects, technical and non-technical, defining specific criteria for each one of them; the main benefits for students are related to changes in behavior, development of soft skills and better absorption of technical knowledge; as main challenges for students, the difficulty to understand the nuances of the proposed problem and to be the main responsible for devising a solution for it without the figure of a teacher to give a clear definition of how to do it stands out.**

Keywords*—*Computing Education, Problem-Based Learning, PBL, Student Assessment

I. INTRODUCTION

Computing education has many challenges, as it requires the development of various skills in students, often subjective and difficult to assess [1], [2]. [3]. In fact, technical knowledge alone is not enough to train a computer professional, but interpretive and logical skills related to problem-solving and non-technical skills, such as group work, creativity, critical vision, collaboration, and communication [3], [4], [5]. The use of active learning methodologies such as PBL (Problem-Based Learning) [6] is an effective alternative to deal with such requirements in the area, considering that this approach can develop technical and non-technical skills to solve real problems.

PBL is defined as an instructional teaching model based on constructivism [6], using real problems as an object of learning and group work as a practical strategy. This learning approach also motivates students to participate in the pedagogical process as active actors, bringing students to the center of the teaching and learning process and placing teachers in the role of advisor and facilitator in this process [7].

In [3], a study that evaluates about 100 PBL studies in the computing area in the last decades highlights this approach's effectiveness for teaching practical disciplines, such as software and systems engineering, and its ability to develop diverse student competencies. The studies have also shown a great concern with the student assessment process in recent years to monitor and prove the benefits of PBL, making it clear that there are still many challenges [3]. These studies can highlight some recurring questions: *How to assess whether each individual contributes to the problem solving and learning process*? *How do you know if everyone is collaborating in group work*? *How do you know if technical and non-technical skills are being developed*? In this context, the need for evaluation models and metrics to monitor the PBL approach is evident, which motivated the study described in this paper to understand the nuances of the assessment process in computing education.

This research used the Systematic Literature Review (SLR) method proposed by Kitchenham [8] in three stages: 1) planning the review; 2) conducting the review and; 3) discussion of the studies. Thus, this paper follows these stages to present its results.

This paper is divided into five sections. After this brief introduction, Section II presents the main theoretical references to fundament the research and its analysis. Section III describes the application of the SLR method by Kitchenham. Section IV presents and discusses the results found, and finally, Section V comments on the conclusions and future works.

II. THEORETICAL REFERENCES

A. PBL in Computing Education

Problem-Based Learning (PBL) is an instructional model of constructivist teaching and learning that, unlike traditional approaches, uses practical problems and contextualized with reality to conduct learning to develop skills related to problem-solving [9]. The PBL follows a strategy of encouraging teamwork that, consequently, develops other interpersonal skills in students, in addition to a change in their attitudes, making them more proactive and responsible for conducting the problem-solving process, assuming a role active in your own learning [10], [11].

Although the PBL was created in Medical Education, the proposal of this approach when applied to the Computing context presents very positive results, considering that the characteristic of using real problems related to the needs of the market tends to be able to align the theoretical content understood by students with the professional practice [12].

As proposed in [13], the PBL applied to the teaching of Computing is based on 10 principles, defined to highlight the relevance of the problem and the need for changes in the teaching and learning process. Are they: 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*. Preserving the PBL principles can guarantee the benefits that the approach advocates through a more collaborative, experienced, and reflective learning process.

Despite the obvious benefits of PBL, according to [9], its dynamic nature results in difficulty in evaluating the results of the teaching and learning experience [14]. The verification of the conformity between the assimilated knowledge and the educational objectives must then take into account different perspectives. Thus, even though the PBL is able to represent a positive alternative to the educational problems of traditional teaching, it is necessary to investigate further points of view regarding the assessment strategies in this context [11].

B. Assessment in PBL-Based Teaching Computing

Given the principles of PBL (specially principles 8, 9, and 10), it is important to consider some important characteristics in the definition of an assessment model for this approach: *assessment throughout the learning process*, exploring aspects related not only technical knowledge but to the resolution process itself; *assessment of the perception of everyone involved* in the learning environment, including students' self-assessment; *evaluation of teaching and learning methodology*, aiming at conformity with its principles.

As noted by [13], PBL has several intrinsic characteristics that make it unpredictable, dynamic, and flexible, since it takes place in a practical context, which involves a process of assimilation of different curricular aspects, in an environment that is often different from the reality of the students. Thus, [13] comments that the PBL context assessment tends to be less effective if it does not contemplate several aspects related to the learning process, including the improvisation factor. This tends to happen constantly both on the part of students, as they are usually used to having a well-defined process of solving problems, and on the part of teachers, considering that they are used to being the center of the process.

For Alias, Masek, and Salleh [15], it is important that strategies are carried out and built to carry out student evaluations both by peers and themselves that they have tools and feedback to become independent. Such an assessment provides indicators not only so that the student itself can reflect and seek to improve but also so that the pedagogical team responsible for conducting the PBL learning process can reevaluate its strategy, seeking to ensure educational objectives. Student assessment by the teaching team remains essential since this team is responsible for planning and conducting the PBL approach; therefore, it is necessary to investigate whether the process is being conducted properly and following the principles established by the PBL [12]. Also, the evaluation of the pedagogical team can provide indicators to guarantee the learning process's quality.

According to Oliveira et al., as mentioned by [9], several educational methods claim to be PBL used in different contexts. The big problem is that cases often reported as PBL are not concerned with ensuring that the process runs according to defined principles. Thus, to ensure that the methodology is being carried out correctly, following the proposed principles, the evaluative models used in the teaching experiences must consider the methodology's evaluation to guarantee the authenticity of the learning environment and the effectiveness of the method [13].

Specifically on the characteristic of *authenticity*, it is important to highlight the concepts of authentic evaluation proposed by Herrington and Herrington [16]. This study proposes seven essential elements in an authentic assessment, fully aligned with the PBL: 1)The context must be real, thus reflecting the conditions for assessing student performance in this context; 2) Students need to participate effectively in solving problems, as doers, based on the knowledge acquired during training; 3) Students need to devote time and effort to collaborate with others involved in problem-solving; 4) The problem must be real and of relevant complexity; 5) The assessment process and the student activities are integrated; 6) The assessment should include several performance indicators; 7) Indicators need to have well-defined and reliable criteria. Based on [16], [11] proposes an assessment model called *PBL-SEE* to provide strategies to evaluate the effectiveness of PBL for the teaching of computing. This model considers three perspectives: student assessment; evaluation of the PBL methodology used; teacher/course evaluation. For the student perspective, the focus of this current study, the model proposes the evaluation of five aspects: *Content*, with a focus on knowledge and technical understanding of the subject in question; *Process*, focusing on the problem-solving process defined by the students; *Output*, considering the production of artifacts and their quality; *Performance*, focused on the assessment of soft skills; and *Client satisfaction*, referring to criteria defined by the real client of the solution, which involves relationship management and compliance with what was planned. Each aspect is related to one objective educational based on the Revised Bloom's Taxonomy [17], allowing the monitoring of student learning: to know and understand concepts and fundamentals applicable to problem-solving (*Content)*; to apply acquired knowledge to solve problems (*Output*); to evaluate proposed solutions against the actual client's criteria (*Client satisfaction)*; to assess one's own interpersonal skills and those of one's team (*Performance*); and to analyze and create/adapt resolution processes that best apply to the problem situation (*Process)*. Because it considers diverse aspects, this reference is used to discuss the findings of the research question RQ1.

Finally, it is important to consider the periodicity of the evaluations, in general, related to their modality. It is possible to implement assessments in three modalities: *diagnostic*, *formative*, and *summative*. According to [18], diagnostic assessments are normally applied at the beginning of the teaching experience to identify the student's previous knowledge about what he intends to learn, in addition to investigating whether the student has the prerequisites for learning new knowledge and/or expertise. A formative assessment is characterized by verifying and monitoring the student's learning continuity during the teaching process, investigating whether the defined educational objectives are being achieved. Through this type of evaluation, the pedagogical team can carry out interventions in the teaching process, aiming to readjust it according to the results obtained and improve the students' learning [12]. Finally, the summative assessment is the most popularly used in traditional education, usually applied as an individual assessment. The purpose of this assessment is to classify the student as to their learning at the end of the teaching experience, usually assigning a grade relative to how much of the general content the student has learned [18]. The choice of which type of assessment should be adopted depends on the defined educational objectives. On the one hand, the characteristic of the PBL for the development of soft skills, built iteratively, is more in line with formative assessments. On the other hand, combining these modalities in a balanced way can greatly favor the PBL approach and the management of the teaching and learning process [18].

As mentioned in [13], despite the understanding of the principles of PBL and the characteristics of the assessment process in this approach, there is no consensus on how to define an assessment model for PBL-based education best. Therefore, it is important to investigate experiences that may support future definitions of assessment models.

III. Research Method

This study used a method based on Kitchenham [8]. It consists of three main stages, being: 1) *planning the review*, identifying the motivation, and defining the protocol to be followed; 2) *conducting the review*, following the defined protocol, extracting, and synthesizing the data; 3) *discussion of the studies*, based on the answers found for the research questions.

A. Planning the Review

In the first phase, we did some activities with the purpose of having a better understanding of the problem, identifying its context, motivation, and relevance, as discussed in Section II. After, we defined six research questions to guide the search and selection processes:

- *RQ1*) What assessment models are being used?
- *RQ2*) Which aspects are evaluated?
- *RQ3*) What criteria and media have been defined?
- *RQ4*) Who gets involved in the assessment process?
- *RQ5*) What is the ideal frequency to conduct the evaluations?
- *RQ6*) What can these models reveal?

These questions concern *assessment models*, considering the structured models proposed in the studies; *evaluation aspects*, related to the five aspects in [11] (content, process, results, performance, and client satisfaction) and its characteristics (criteria, people involved, and periodicity); and, finally, what *results and impact* identified from the assessment processes. To answer these research questions, we used a generic search string defined in [3], including search terms concerns computing area, PBL, and their synonyms, as shown in Table I. We avoided the acronym "PBL" due to several studies on "project" based learning using the same acronym. We test the search string using an iterative approach, refining it with the help of four researchers: one master student; two Ph.D. students in PBL and; one PBL specialist, with more than 10 years of experience in PBL and computing education research, as described in [3]. With this string, we used the automatic search engines of four research bases: ACM, IEEEXplore, Scopus, and Science Direct (SD). These bases were chosen for their representativeness for the computing area. The automated search process was restricted to the range of papers published from 1997 to 2019.

TABLE I. SEARCH STRING

(learning OR learner OR education OR methodology OR approach OR "educational program" OR constructivism OR constructivist OR method) AND ("problem based learning" OR "problem based learned" OR "problem-based learning") AND (computer OR software OR "computer engineering" OR "information technology" OR "computer science")[a]

[a] Source in [3]

It is important to emphasized that, the study in [3] carried out a systematic mapping of PBL in computing education, identifying a hundred studies in the context of current research interest. Therefore, we used the studies selected in [3] as input for the current systematic review, redefining new criteria related to assessment models.

B. Conducting the Review

The primary studies found in the paper in [3] initially considered the period from 1997 to 2019 but excluded the papers from 1997 to 1998, maintaining the period of 1999 to 2019 concerning two decades. The current study considered the initial period (1997 to 2019), resulting in 105 primary studies, distributed according to Table II. A two-step procedure, conducted by two researchers (both undergraduate students of computing), was carried out to select the articles that could answer the research questions in Table I.

TABLE II. SELECTION PROCESS

Source	***Studies in [3]***	***Exclusion Criterium***	***Quality Criteria***
ACM	11	6	5
IEEE	61	36	23
Science Direct	3	1	0
Scopus	30	28	19
Total:	105	71	**47**

First, as the articles were already qualified concerning several criteria and already belonged to computing education in the PBL approach, we adopted only one exclusion criterion: studies do not align with the theme about assessment models. Second, the researchers analyzed the studies under specific quality criteria: 1) Relevance to the study area/central theme; 2) Completeness and clarity of the content about assessment models; 3) Response to research questions. To apply the quality criteria, a scale of three values was considered: 0 (not attend), 0.5 (partially attend), and 1 (attend). From that second step, a total of 47 primary studies were obtained. A complete list of the studies is presented at the end of this paper, using the acronymous "PS" to "Primary Study".

As extraction data were defined: title and authors of the paper; year of publication; study goals; research context, and text related to research questions (details about assessment models). Two researchers have collected data, organizing data per basis. In the selection steps, a PBL specialist was involved advising how to collect data in order to answer each research question.

C. Reporting the Review

Figure 1 shows the 47 selected studies over time. There is a concentration of studies published in the last 5 years, with a considerable increase in the last two years (2018 and 2019). In addition, it is noticeable that in the first 15 years, few PBL studies showed well-structured proposals focusing on the evaluation model, although this reality has been changing recently.

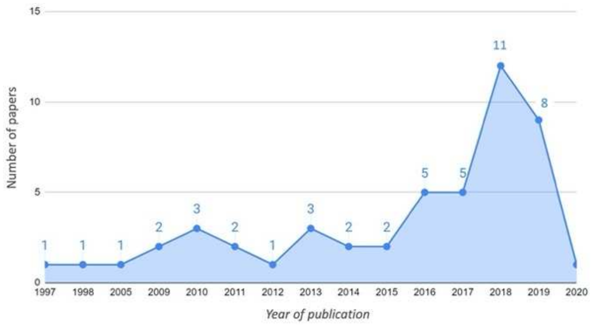

Fig. 1. Papers over time

Most of the experiences of the analyzed studies occurred within the scope of the undergraduate course, as shown in Figure 2.

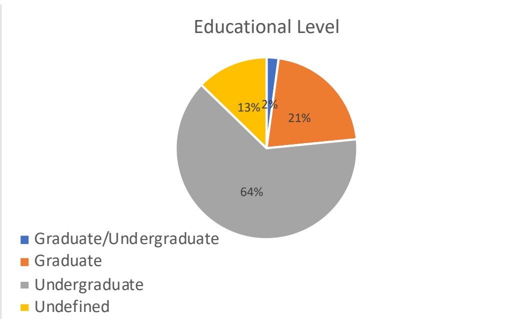

Fig. 2. Educational level of case studies

Considering the evidence found, it is possible to conclude that undergraduate students lack more practical skills and knowledge, normally acquired when integrating into the job market. Therefore, the adoption of PBL contributes to the training of these students by participating in a teaching experience with a focus on practical and real problems. The following study highlights: "*Graduates in the field of computing are not only expected to acquire a substantial body of knowledge and a wide set of skills; they are also expected to be able to identify problems and create systems.*" [PS02]. Another study reinforces this characteristic when it clarifies the objective of the educational program: "*The aim of the program is to provide a greater amount of practical learning during the semester and give students the opportunity to experience the key demands made by the labor market in recent years.*" [PS47]. Most of the experiments had the educational objective of teaching technical content within the computing area (Figure 3), using PBL as a methodology. Still, on the objectives, five of them reported that the educational objective was aimed at offering participants the experience of solving a real problem.

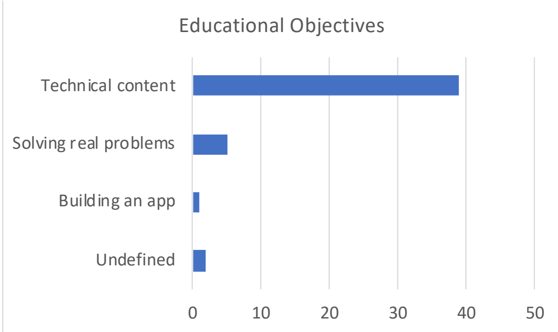

Fig. 3. Educational objectives of studies.

Interestingly, not all experiences analyzed were concerned with detailing their educational objectives but commenting on the technical course or the technical content to be taught. In general, most teaching experiences commented on the students' ability to relate technical content to the needs of the labor market or a real context. In this way, we can see a concern with the alignment between theory and practice, as reinforced in [PS24]: "*Establishing a relationship between Software Engineering theory and practice, producing perceivable results that demonstrate the skills developed by the students.*" Among the experiences related to the teaching of technical content, we also observed a wide variety of topics. However, it is possible to note a predominance of the topic programming/software design. Figure 4 summarizes these topics in a word cloud, built from the extraction of the terms described by the studies as their educational objective.

Fig. 4. Main topics commented in the studies.

Finally, this analysis also considered the duration of the experiments. Of the 47 experiences analyzed, about 38 studies reported the duration of the educational unit: 24 studies lasting between 3 to 6 months; 9 studies lasting more than 6 months and; only 5 studies lasting up to 1 month. The shortest experiences are reported in [PS07], [PS31], [PS37], while the longest (3 years in duration) are reported in [PS23] and [PS25]. The most frequent duration found was 6 months, present in eight studies ([PS16], [PS30], [PS33], [PS35], [PS40], [PS43], [PS45], and [PS46]).

D. Limitations and Threats to Validity

Some limitations can be observed, mainly related to the study selection process, since the results of the systematic mapping performed in [3] were considered as a starting point for the current study. Thus, this study assumes the limitations and threats of the original study, in which relevant studies may not have been considered. Another limitation inherent to systematic reviews, with qualitative characteristics, is the possibility of misinterpretation in the selection and analysis of studies related to the topic in question. To reduce the impacts of this characteristic, we used the strategy recommended by Kitchenham [8] to involve more than one person responsible for the selection and a reviewer specialized in PBL, seeking to guarantee the quality of the analysis.

IV. Results & Discussion

A. Assessment models

Concerning the RQ1, few studies have presented their proposal for assessing the student as a *structured model*. The vast majority focused on the learning process, using information about the evaluation process to comment on the monitoring and results of this process. Among the studies focused on the assessment model, the [PS02], [PS10], [PS13], [PS20], [PS36] and [PS38] stand out.

[PS02] proposes a model to evaluate each individual's contribution under the aspect of group work, generic enough to be used in different contexts. As can be seen, an evaluation scale of 4 values is proposed, related to how much a particular member of the group contributed by demonstrating a specific skill. The proposed form proposes the suggestion to be applied in three moments of the course: at the begin, in the middle, and at the end. As for the skills being assessed, it presents a varied listing of different behaviors and attitudes such as "*Expressed individual opinion*s" and "*Listened actively*"

In [PS10], a cyclical evaluation model is proposed, structured to evaluate different aspects and perspectives, considering four stages: *Preparation*, planning, and preparation of the criteria and methods of evaluation; *Diagnostic*, to identify your current level of knowledge about the content to be worked on; *Monitoring*, contemplating continuous evaluations, seeking to identify possible gaps in learning in terms of content, process and deliveries; *Classification*, development phase and application of summative assessments to verify the student's learning outcome.

In [PS13], an Authentic Assessment Model is proposed that aims to assess the student from different perspectives, providing more relevant indicators. This study was a precursor to the study in [PS20], commented on in Section II, which proposes assessing the student based on the 5 aspects used as a reference in the current study (Content, Process, Results, Performance, and Client Satisfaction).

In [PS36], a structured evaluation model, the Q-PBL, is also proposed. In summary, this instrument assesses 17 items related to specific aspects of the PBL's own dynamics (motivation, tutorial session, tutorial group, problem, tutor, evaluation and feedback, adaptation) and the perception of 9 skills improved from this method (problem-solving, self-directed learning, interpersonal relationships, oral expression, written expression, text interpretation, planning, group work and capacity for reflection).

Finally, [PS38] proposes to evaluate the students' individual study method and the process of reflection on their learning, aiming to establish a relationship between this self-assessment and the student's attitudes during the PBL teaching experience.

B. Assessing Students

To investigate how student assessments are being conducted even without the definition of a formal model, this section presents and discusses the main evidence collected in response to research questions RQ2 to RQ5. To facilitate the discussion, the model proposed in [11] was used as a reference, commented on in Section II, which proposes five aspects of evaluation: Understanding the technical content worked on (*Content)*; Quality of the solution produced and delivered (*Output*); Knowledge about the proposed problem-solving process (*Process*); Personal skills and attitudes, in general, related to soft skills (*Perfomance*); Vision of the real client regarding fulfilling their needs and planning (*Client satisfaction*).

For better understanding and visualization, the aspects were also related from two perspectives: technical (*hard skills*) and non-technical (*soft skills*). For each identified aspect, studies that consider it within their respective study were associated, as shown in Table III.

TABLE III. Assessment aspects

Source	***Skills***	***Aspects***
Content	Hard	Knowledge and understanding of the content taught [PS01, PS08, PS10, PS11, PS12, PS13, PS16, PS18, PS19, PS20, PS29, PS30, PS31, PS37, PS38]
Result	Hard	The solution produced and delivered [PS02, PS08, PS11, PS12, PS13, PS15, PS20, PS25, PS26, PS31, PS33, PS34, PS35]
Process	Hard	Mastery of the resolution process [PS08, PS18, PS25, PS32, PS42, PS45]
Performance	Soft	Self-management [PS44] Self-development [PS07, PS13, PS15, PS35,PS36] Self-Initiative [PS12, PS13, PS18, PS19, PS29, PS32, PS34, PS42, PS45] Collaboration [PS07, PS12, PS15, PS18, PS19, PS32, PS34, PS45] Commitment [PS18, PS19, PS32, PS34,PS42,PS45] Communication [PS12, PS13, PS15, PS18, PS19, PS32, PS34, PS36, PS42, PS44, PS45] Confidence [PS29] Creativity [PS42, PS44, PS45] Dialectical thinking [PS07] Ease of learning [PS12, PS13] Flexibility [PS13] Focus on results [PS12, PS13] Presentation skills [PS25] Leadership [PS44] Group work [PS13, PS31, PS36] Engagement [PS32, PS33, PS42, PS43, PS45] Motivation [PS07, PS15, PS43]
Client Satisfaction	Hard & Soft	Relationship management and compliance with what was planned [PS11, PS12, PS13, PS15, PS18, PS20, PS32, PS45]

Looking at Table IV, it is possible to clearly see the concern with the personal aspects of students in studies based on the PBL approach. Several soft skills have been mapped in this context, making evident the method's suitability for stimulating both technical and non-technical skills. On the other hand, two aspects proved to be little addressed in the evaluation models: process and customer satisfaction. It is important to note that these aspects are fundamental in the PBL approach concerning the problem-solving process, which will give the student the ability to solve new problems, and the authenticity of the learning environment, preparing the student for situations in your professional life.

Concerning each of these five aspects, it was possible to identify more details about how they were conducted in the studies, considering: the criteria and media of evaluation used (RQ3), who conducted the evaluation (RQ4), and what is the frequency of these evaluations (RQ5). Tables IV to VIII describe these details for each aspect of the assessment.

Regarding the Content aspect (Table IV), we can see a predominance of teachers in the evaluation of the student, much more usual in the summative modality (end of the experiment) than in the formative one (throughout the learning process). Self-assessment appears as a diagnostic assessment tool applied at the beginning of the course. As for the adopted criteria, we also can note the questioning about the knowledge and understanding of the content through objective or subjective tests, considering the summative modality, and monitoring this understanding throughout the learning process through questionnaires, considering the formative modality.

TABLE IV. CONTENT ASPECT

Who evaluates	*Criteria*	*Evaluation Media*	*Periodicity*
Teacher [PS01, PS08, PS11, PS12, PS13, PS15, PS18, PS19, PS20, PS29, PS30, PS31]	Open and closed questions about taught content [PS01, PS08, PS10, PS11, PS13, PS19, PS29, PS30, PS37, PS38]	Objective and subjective Tests [PS01, PS08, PS10, PS16, PS18, PS19, PS30, PS31, PS38]	At the end of the experiment (Summative) [PS01, PS10, PS11, PS08, PS13, PS16, PS29, PS30, PS31, PS37 PS38]
Researchers [PS38]	Evolution of understanding about content during the experience [PS01, PS10, PS18]	Questionnaires [PS11, PS13, PS37]	During the experience (Formative) [PS01, PS10, PS18, PS20, PS30, PS37]
Self-assessment [PS37]	The initial level of knowledge about the content to be worked on [PS10, PS38]	Interviews [PS10], Feedbacks [PS10, PS30]	At the beginning of the experiment (Diagnosis) [PS10, PS38]

Concerning the Output aspect (Table V), new actors appear conducting the evaluation process beyond the teacher, such as the technical tutor and the committee of experts.

TABLE V. OUTPUT ASPECT

Who evaluates	*Criteria*	*Evaluation Media*	*Periodicity*
Teacher [PS02, PS08, PS15, PS26, PS31, PS35]	Quality of the delivered solution [PS12, PS15, PS25, PS26, PS31, PS34, PS35]	Analysis of the delivered solution [PS12, PS15, PS25, PS26, PS34]	At the end of the experiment (Summative) [PS02, PS08, PS11, PS12, PS15, PS25, PS31, PS33]
Technical tutor [PS11, PS13, PS20]	Quality of the delivered code [EP02, EP11, EP13, EP25, EP35]	Source code of the delivered solution [PS02, PS11, PS13, PS25, PS31, PS33]	During the experience (Formative) [PS12, PS13, PS20, PS34]
Expert committee [PS33]	Knowledge about the project [PS02]	Presentations [PS02, PS08, PS25, PS31, PS33]	During the experience (Formative) - At the end of each sprint [PS13, PS20]

The criteria used are related to the quality of deliveries (codes, software, documents, applications), varying according to the characteristics of these deliveries. In most studies, these assessments are carried out at the end of the course (summative). However, some studies present formative evaluations that analyzing partial results of a project and providing continuous feedback throughout the course.

According to the studies, the teacher, technical tutor, or an external collaborator (representing a real client) can evaluate the Process aspect (Table VI). This aspect aims to verify that students have understood the problem to be solved and the solving process, appropriating procedures to help them solve new and different problems. These assessments can be carried out through questionnaires, presentations, and reports. Although it can be conducted in both formative and summative modalities, the construction of this competence follows an evolutionary process, therefore, more aligned with formative assessments.

TABLE VI. PROCESS ASPECT

Who evaluates	*Criteria*	*Evaluation Media*	*Periodicity*
Teacher [PS08, PS18, PS42]	Knowledge of the problems and difficulties of the resolution process: - Process questions - Rich details - Knowledge about the decisions - Understanding the resolution - Process communication	Questionnaires [PS32, PS42]	At the end of the experiment (Summative) [PS08, PS32, PS42, PS45]
Technical tutor [PS18, PS42]		Presentations [PS08, PS18, PS45]	
External collaborators [PS42]		Report [PS08]	During the experience (Formative) [PS18, PS20, PS32, PS45]

The Performance aspect (Table VII), related to the assessment of soft skills, one of the most recurrent in the studies found, has been mostly applied as self-assessment and assessment by the student's team members.

TABLE VII. PERFORMANCE ASPECT

Who evaluates	*Criteria*	*Evaluation Media*	*Periodicity*
Self-evaluation [PS12, PS13, PS15, PS18, PS19, PS31, PS34, PS35, PS36, PS37, PS42, PS44]	List of skills to analyze how much the skill/attitude was demonstrated/ improved. [EP12, EP13, PS15, PS18, PS19, PS29, PS31, PS32, PS34, PS36, PS37, PS42, PS44, PS45]	Questionnaires [PS11, PS13, PS37]	At the end of the experiment (Summative) [PS08, PS32, PS42, PS45]
Group members [PS13, PS18, PS19, PS31, PS32, PS34, PS45]		Forms [PS13, PS15, PS18, PS32, PS35, PS42, PS45]	During the experience (Formative) [EP13, PS20, PS25, PS31, PS32, PS33, PS36, PS37, PS42, PS45]
Teacher [PS29, PS42, PS43] and Technical Leader [PS13]		360-degree evaluation [PS19, PS31, PS34]	During the experience - weekly (Formative) [PS25, PS31]

Few studies show the teacher acting as an evaluator, considering that he is not always present during the problem-solving process but occasionally in follow-up moments. As criteria used, the studies showed a vast list of skills and attitudes such as communication, collaboration, leadership, creativity, group work, among others. These assessments are usually applied through forms or questionnaires, sometimes collecting multiple feedbacks from the student himself, his peers, and the group's technical leader (360-degree assessment). The assessment at various times in the formative modality, allowing continuous feedback to students, is also the most used.

Finally, the Customer Satisfaction aspect (Table VIII), as the proposal itself indicates, has been applied to involve professionals from the market professionals or specialists in the software industry as members of the pedagogical team, allowing them to assess the student and his/her behavior in the team (such as Computer professionals), besides the proposed solutions from the perspective of the labor market. As criteria used, the quality of the proposed solution, the teams' interaction with the real customer, and the team's management capacity stand out. These evaluations have been carried out through presentations and reports of the projects, allowing the external collaborator to interact, monitor, and contribute to resolving real problems throughout the course, evaluating the teams continuously (formative modality).

TABLE VIII. CLIENT SATISFACTION ASPECT

Who evaluates	***Criteria***	***Evaluation Media***	***Periodicity***
External Collaborators [PS11, PS12, PS13, PS18, PS20, PS32, PS45]	Projection of confidence in interviews; understanding of the problems; clarity of presentation; quality of the solutions proposed; level of planning. [PS11, PS12, PS13, PS18, PS20, PS32, PS45]	Presentations and Reports [PS11, PS12, PS13, PS18, PS20, PS32, PS45]	During the experience (Formative) [PS11, PS12, PS13, PS18, PS20, PS32, PS45]

C. *RQ6 - What can these models reveal?*

Most studies analyzed (83%) had some benefit, that is, 39 out of 47 studies. According to Table IX, it is possible to summarize the benefits in three main groups.

TABLE IX. PERCEIVED BENEFIT

Improvement of Soft Skills	***Changes in Attitude and Behavior***	***Improvement of technical knowledge***
• Ability to work in groups • Communication • Leadership • Public speaking • Problem-solving • Relationship Interpersonal • Orality • Self-learning [PS04, PS06-10, PS13, PS16, PS22, PS24-27, PS30, PS33, PS35-37, PS40]	• Projection of More motivated students • Greater proactivity • Increased interaction with classmates • More active participation in teaching • Increased confidence • Enthusiasm for apprenticeship • Larger commitment to your learning • More behavior critical • Breaking zone comfort • Greater interest in extracurricular learning [PS03, PS04, PS06-12, PS15, PS17, PS22, PS24, PS27, PS29-31, PS33, PS35, PS36, PS38-40, PS45]	• Technical skills for developing solutions • A better understanding of programming concepts • Development of better solutions [PS03, PS09, PS25-27, PS32, PS33, PS35, PS36, PS40, PS46]

The benefits related to the improvement of soft skills were reported by 19 studies, highlighting competence such as collaboration, communication, proactivity, group work, among others. The study [PS24] highlights: "*the results of the research showed up most of the respondents realize that the use of problem-solving assists them into establishing a relationship between theory and practice, developing skills to work collaboratively, and developing a proactive attitude*. The change in attitude and behavior of students has been described in 27 studies, emphasizing the increase in student motivation in this approach. The study [PS30] reports, "*Students are more engaged in their learning: they feel more responsible and also commit more through personal work*." The self-initiative is also highlighted as a reflection of this motivation, as [PS35] reports: "*Positive and proactive attitudes from the students during the game development were evident, especially to autonomously search for new knowledge*." As for the technical aspect of the students, 11 studies pointed to some improvement, as the studies report: "*The PBL approach allowed the acquisition of skills and competencies related to the practice of computer programming in an OOP language."* [PS41]; *"It was also observed an improvement in programming itself, that is, more elaborate and organized codes*." [PS35]. Other results associated with the benefits found also stood out. One of them refers to the stimulation of students with the job market and/or with the desire to work in their area of study. It has been reported the experiences involving practical projects have even increased the rate of student hiring by companies. In addition, by learning more about the applicability of the theoretical subjects seen, students felt more confident working in areas related to their learning. Also, in this context, we percept of the usefulness of the theoretical concepts learned, and its connection with reality was pointed out as a benefit, as the study in [PS30] emphasizes: "*By making them solve current problems, and letting them be confronted to the difficulty of the act of solving, students feel more connected to the reality and view the course as more useful.* ". We found another interesting result related to the pedagogical approach: the increase in students' grades when compared to scenarios with traditional teaching methodologies. Of the 39 studies that showed some benefit, 50% of them reported this result, as highlighted by the studies: *"[...] after being exposed to the PBL methodology, the students improved considerably their grades.*" [PS27]; "*Firstly, the percentage number of PBL students who got A grade are noticeably higher than Non-PBL students. Secondly, the percentage number of Non-PBL students who got C + grade is obviously higher than PBL students. Finally, the percentage number of PBL students who got D/F grade is lower than Non-PBL students.* "[PS16].

Unlike the question regarding benefits, the percentage of studies that presented challenges related to the student was a minority, only 42%. The most frequently perceived challenge was group work by the students, as highlighted in the study [PS30]: "*Secondly, working in group is not always easy, and a group that highly dysfunctions would really hinders the learnings of everyone in the group*". Some other specific challenges related to the student were perceived by the studies, according to Table X.

TABLE X. OCCASIONAL CHALLENGES

Challenges	***Studies***
Difficulty learning the explained concepts	[PS11], [PS18]
Lack of commitment	[PS12], [PS31], [PS41]
Difficulty in dealing with the problem and thinking about the solution	[PS22], [PS32], [PS35], [PS36], [PS38], [PS45]
Students more fatigued	[PS26], [PS41], [PS43]
Difficulty in applying the theoretical content in a practical situation	[PS27], [PS40]
Most stressed students	[PS30]
Lack of proactivity	[PS31]
Unmotivated students	[PS41]

Regarding the difficulty of dealing with the problem/solution, a challenge most indicated in studies, it refers to an expected difficulty, since in the traditional teaching process there is the figure of the teacher defining the problem-solving process, while in this context the student you need to go through the problem understanding and solving phase on your own. The study [PS45] reports this challenge: *"[...] there was a difficulty in the teams to plan their projects, to define tasks and schedules compatible with their resources. This was happened because the students didn't define a consistent resolution process, which is a responsibility assumed by teacher in the traditional approach."*

V. Conclusions

As for student assessment models, few studies have shown the concern to define structured models that could be used in different contexts of PBL. Four main aspects and perspectives were listed as a possibility to evaluate students: 1) Learning the content worked on; 2) Quality of the solution produced and delivered; 3) Knowledge about the resolution process and 4) Analysis of how well the Skills and Attitudes have been developed. We believe that an assessment model that combines several aspects makes it possible to understand the evolution of student learning much more clearly and their contribution to the group's work.

Regarding what should be considered in the evaluation process, attention is needed to what is defined as an educational objective since it will define what will be monitored. So, we strongly recommend that the student's assessment model be adjusted according to educational objectives, considering its respective aspects. An appropriate evaluation model will include: 1) those responsible for evaluating; 2) what criteria should be used; 3) what are the best means of evaluation and 4) the most appropriate periodicity, be it diagnostic, formative, or summative. Unfortunately, regardless of the evaluated aspect or perspective, few experiences considered performing diagnostic evaluations of students, with a more frequent summative evaluation at the end of the experience. The diagnostic evaluation can help define educational objectives, and the formative evaluations allow the intervention along the learning process towards these objectives.

The main positive results perceived through the student's evaluation process are improvement of soft skills; changes in attitude and behavior, and better learning of technical and non-technical knowledge. One of the most prominent soft skills is group work, encouraging students to take an active stance in the problem-solving process. It also highlights the students' motivation for learning and the easier learning of complex concepts. As the next steps, the research group that conducts this study plans to improve the assessment model for computer education proposed in [11], based on the findings and gaps found in this study. An ongoing project also plans to develop software tools that can support the usability and usefulness of this model.

The main challenges perceived in the assessment of students refer to harmonizing group work, understanding the problem, and designing a solution for it. As found in the literature, such difficulty was expected since, at PBL, the student is primarily responsible for understanding the problem and devising a solution, requiring greater resourcefulness and effort. A real opportunity for us to work on aspects of student self-regulation.

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