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Problem-Based Learning to Support Active Learning in an Undergraduate Industrial Engineering Course

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Abstract

This study aimed to implement the Problem-Based Learning methodology in the Cost Management Analysis course and examine its impact on students' learning and perceptions, promoting a more practical, inquiry-driven approach aligned with current educational guidelines. To support the implementation, a fictitious learning factory, called PRODUBISC, was developed as the basis for two course challenges conducted during the first semester of 2025. The evaluation of the methodology was performed through questionnaires administered after each stage, with response rates exceeding 70%. The findings indicate strong acceptance of Problem-Based Learning methodology among students, who highlighted benefits such as the practical application of course content, the development of investigative skills, critical reasoning, and problem-solving. Reported challenges included time management, the need for clearer instructions, and uneven task distribution within groups. The methodology also showed a positive impact on academic performance, particularly in topics directly related to the proposed challenges. Overall, the results demonstrate that PBL is a viable and effective strategy for fostering engagement and active learning in courses traditionally based on theoretical instruction. The creation of PRODUBISC as a pedagogical tool provides a long-term foundation for future course offerings and supports the modernization of teaching practices.

Keywords
Problem-Based Learning, Active Learning; Active Methodologies, Industrial Engineering.

1. Introduction
The National Curriculum Guidelines (DCNs) for Engineering in Brazil are instruments established by the Ministry of Education (MEC) that define competencies, skills, and minimum content to be addressed in undergraduate programs (Dos Santos 2023). Following a global trend, in 2019 an update of this instrument was released, emphasizing the use of active learning methodologies to promote a more student-centered education (Brasil 2019). Some international examples illustrate this trend. In Japan, active learning practices began to be encouraged in higher education programs in 2012 (Matsushita 2018), while in the Netherlands one university has all its programs based on active teaching methodologies (Waniek and Nae 2017). Aligned with these reforms, the Coordination for the Improvement of Higher Education Personnel (CAPES), in cooperation with the Fulbright Commission of Brazil and the U.S. Embassy, launched in 2019 the Brazil–United States Program for the Modernization of Higher Education in Undergraduate Studies (PMG). According to Leiva et al. (2021), one of the goals of the program is to encourage the application of active teaching and learning methodologies to strengthen the Brazilian higher education system. The Industrial Engineering program at the Universidade Federal do Rio Grande do Sul (UFRGS) was selected for the program and has based its modernization process on the adoption of innovative pedagogical practices (Tinoco et al. 2021; Tinoco et al. 2023).

Active learning, compared with traditional methods, has proven effective due to its contribution to students' understanding of difficult concepts. Gusc and Van Veen-Dirks (2017) show that the use of strategies such as flipped classroom, gamification, and problem- or project-based learning enhances students' knowledge and critical and analytical reasoning. Similarly, Forni et al. (2017) and Vales and Santos (2018) highlight how such methods contribute to forming more competent professionals. Among the existing active learning practices, Problem-Based Learning (PBL) plays a prominent role. According to Savary (2006), PBL consists of applying knowledge and skills to develop and solve a defined problem. In this context, this study aims to implement the PBL methodology in the 'Cost Management Analysis' course and examine its effects on students' learning, engagement, and perceptions of the teaching–learning process.

The content addressed in this course belongs to the Economic Engineering domain, one of the ten knowledge areas of the Industrial Engineering undergraduate curriculum (ABEPRO 2023). Currently, teaching in the course relies on traditional approaches such as lectures and standardized problem sets, in which students are responsible only for performing calculations after receiving complete data. With the adoption of PBL, an increase in engagement and in the development of students' skills is expected, as discussed by Khaleel et al. (2017). To achieve the objective of this study, a fictional standard learning factory was developed to support the application of course concepts through a challenge involving the implementation of the factory's costing system. As part of the learning process, students are required to perform the stages of data collection and the generation of control indicators, steps traditionally provided by the instructor in the conventional teaching model. Under PBL, students must assume full responsibility for both data generation and the modeling of the costing system. The goal is to calculate the production cost of PRODUBISC's products, which are cookies, requiring the calculation of direct costs (raw materials and packaging) and indirect costs (labor, equipment, and infrastructure). The adoption of PBL for this content is justified, as the course consistently shows high failure rates and covers content that is conceptually demanding and challenging for students.

Within the scope of the PMG, several initiatives have been developed to introduce active learning practices into different Industrial Engineering courses at UFRGS. Practices such as seminars, teamwork, gamification, and flipped classroom are present in the curriculum, although applied in a dispersed and fragmentedly. Overall, most courses emphasize group assignments that encourage students to develop communication and leadership competencies. In the specific case of the course Cost Management Analysis, traditional teaching methods still predominate. Although group work is already part of the semester's activities, the modernization efforts of the program motivated the adoption of PBL as an opportunity to connect course activities with professional practice and to strengthen knowledge retention among students. Beyond its direct impact on student learning, particularly in developing skills highly valued in the labor market, this case may serve as a reference for designing new teaching approaches in the program (Tinoco et al. 2021).

1.1 Objectives

The objective of this study is to implement the Problem-Based Learning (PBL) methodology in the course *Cost Management Analysis* and to analyze its effects on students' learning, engagement, and perceptions. By introducing a fictional learning factory and requiring students to conduct data collection, indicator generation, and costing system modeling, the study seeks to evaluate how PBL can enhance the development of competencies associated with Cost Management within Industrial Engineering education.

2. Literature Review

The traditional approach to knowledge transmission, based on expository, passive lectures, is limited in preparing future engineers to address complex, multidisciplinary problems, as noted by Valença (2023). In contrast, active learning methodologies can be seen as a shift in perspective in the transmission of knowledge. Whereas previously the focus of traditional approaches was on how the professor taught, the current emphasis is on how the student learns. In this way, the student assumes co-responsibility for their own learning, as discussed by Souza et al. (2014). Through the application and implementation of these learning methodologies, higher education in engineering has been seeking to adapt to better meet the needs of the job market. Among these needs, transversal skills stand out, such as teamwork, effective communication, and critical thinking. Guerra et al. (2017) highlight that these competencies are essential for preparing future engineers for highly volatile scenarios characterized by rapid change, uncertainties, and complexities, as also emphasized by Meixell et al. (2015).

PBL aims to address problems drawn from situations that approximate or represent real-world contexts. Ribeiro (2010) argues that this delineation is essential because it generates an autonomous, critical, and deep learning experience, oriented toward the demands of students' future professional practice. In this methodology, a problem is presented at the beginning of the learning cycle, providing context and motivation throughout the process, with emphasis on the path toward the solution, as observed by Prince (2004). PBL is a collaborative, constructive, and contextualized teaching methodology. It makes use of problem situations to guide and motivate the learning process of concepts, as well as to develop transversal skills such as leadership, communication, teamwork, and proactivity (Sesoko and Neto 2014; Araújo et al. 2025). This model is based on self-directed learning rather than traditional teaching, although the figure of the professor remains present. Branda (2018) explains that the student becomes the main actor in the acquisition of knowledge, while the teacher acts as a facilitator of the learning process, with all participants working cooperatively to find solutions.

The decisions and considerations made in PBL, along with the questions raised during the process, encourage students to explore other areas of knowledge to solve the problem presented. Once the problem is defined, students must seek the necessary knowledge to resolve it, developing skills and attitudes relevant to problem-solving. It is the professor's responsibility to monitor the process, make corrections if needed, and verify whether the knowledge being developed is relevant to the subject and contributes to problem resolution (Araújo et al. 2016; Sesoko and Neto 2014; Araújo et al., 2025). According to Araújo et al. (2016), a PBL format should include several key elements: (i) a real-life problem preceding any discussion of theory; (ii) a formal problem-solving process; (iii) collaborative work in groups; (iv) self-regulated and autonomous study; and (v) integration of knowledge across different domains.

For the successful implementation of PBL, a structured work plan organized around sessions (or classes) is required, each with clear objectives and tasks that contribute to solving the presented problem. Ribeiro and Filho (2008) describe that the first session includes an introduction to the PBL methodology, the formation of teams, presentation of the work plan and learning objectives, and the introduction of the real (or potentially real) problem. Students then begin working on the PBL process, aiming to accurately identify the problem to be solved.

In the subsequent stage, students must gather the necessary knowledge to address the problem. This requires formulating research questions related to the core issue. The teacher acts as a tutor, ensuring that groups remain on the right track (Araújo et al. 2016; Cerqueira et al. 2016). Between sessions, teams continue researching, constructing hypotheses, and proposing solutions. In the second session, they present their progress and receive feedback from the teacher, refining their hypotheses. Cerqueira et al. (2016) highlight that different approaches across teams may result in distinct solutions to the same problem, enriching learning through the exchange of information. At the end of the process, students prepare and deliver a final presentation.

After the problem-execution phase and continuous monitoring by the teacher, it becomes essential to use assessment methods adapted to active learning, following a logic of motivating supervision and self-regulation. Sá et al. (2014) define formative assessment as a continuous practice whose main purpose is to improve teaching and learning processes through ongoing regulation. This type of assessment gathers information that enables students to learn more effectively and/or correct their mistakes, and it also allows teachers to improve their teaching practice, as explained by Nuño (2012). Within the context of active learning, "giving feedback" refers to sending return messages, bidirectionally, from teachers to students and from students to teachers, with the aim of improving the process. This is commonly referred to in the literature as interactive feedback (Torrano and González 2004). Feedback from teachers to students aims at regulating their academic activities, enabling subsequent improvements. Conversely, student feedback to teachers is used to regulate teaching methodologies and classroom practices in a reflective manner.

3. Methods

The data collection was organized into three phases: Planning, Implementation, and Evaluation. In the Planning phase, two tasks were carried out: (i) development of the Standard Learning Factory and (ii) construction of the baseline costing system. In the Implementation phase, two tasks followed: (iii) presentation of the challenges to students and (iv) guidance during execution. The Evaluation phase comprised (v) administration of the questionnaire and (vi) analysis of the results.

3.1. Planning Phase

In the Planning phase, the initial activity consisted of designing a fictional learning factory in the food industry, called PRODUBISC. From the conceptualization to the detailed configuration, each stage was reviewed and validated by faculty members of the Industrial Engineering program at UFRGS. To ensure realism, a real company from the sector was analyzed, allowing the simulated environment to accurately reflect current industrial practices while remaining adaptable for future iterations. The fictional factory employs approximately 50 workers and produces more than 20 items, primarily cookie products. Despite its growth, the company lacks an effective cost management system. To address this gap, two costing approaches were integrated: Standard Cost method (SC), used to analyze direct costs as raw material and packaging expenses, and the Production Effort Unit (PEU) method, applied to indirect costs, such as labor, equipment and infrastructure. The production structure comprises 13 operating stations supported by 31 machines, and the products analyzed use around 18 distinct raw materials. Product recipes were defined and validated according to market practices to ensure applicability. Following the structural definition of the company, the baseline costing system was developed. SC calculations were based on product recipes and supplier information for raw materials, while the PEU method was constructed from operational data collected during the planning phase. The final product cost resulted from the combination of direct (SC) and indirect (PEU) costs.

3.2. Application Phase

The PBL challenge was implemented in two instructional sessions. In the first session, the instructor introduced the problem and clarified technical terms, ensuring that students shared a common understanding of the scenario. During this initial meeting, students engaged in the preliminary stages of the PBL cycle, which included clarifying the problem and defining the specific issue to be addressed. After the presentation of the challenge, the groups discussed unfamiliar elements and raised questions that required explanation. Once the problem was clearly established, students began to search for the knowledge necessary to address it, formulating research questions aligned with the central challenge. Between sessions, the instructor assumed a tutoring role, answering questions and guiding teams toward appropriate solution paths. During this interval, students defined their learning objectives and carried out individual study to identify possible strategies for solving the problem. Although a recommended bibliography offered initial direction, students were encouraged to consult additional sources to broaden their understanding. At the beginning of the second session, students summarized the previous steps, compared ideas, consolidated prior knowledge, and refined the hypotheses developed throughout the process. Each group then presented its proposed solution to the class. This sequence of activities was applied in both components of the challenge, the SC phase and the PEU phase.

3.3. Evaluation Phase

A questionnaire was administered to evaluate whether the advantages and benefits associated with PBL were reflected in its implementation in the Industrial Engineering program at UFRGS. The instrument examined students' perceptions regarding the development of technical and transversal competencies aligned with professional demands, addressing dimensions such as overall evaluation of the methodology, connection between the challenges and course content, learning outcomes, difficulties encountered, comparisons with traditional instruction, and open comments. The design of the questionnaire incorporated improvement opportunities previously reported in the literature, including the need for adequate support during PBL activities, which informed the inclusion of a broader set of items to systematically assess students' experience. In addition, before presenting the results of the case, students completed a traditional group exercise, allowing a direct comparison between conventional teaching and the PBL-based method.

4. Results and Discussion

4.1. Planning

Grounded in the operations of a real food-industry company, the virtual learning factory PRODUBISC was developed to reproduce key characteristics of an authentic industrial environment. This alignment enhances the realism of the learning experience and supports the development of professional competencies expected from Industrial Engineering graduates. The factory mirrors the logic of industrial processes from the reference company, maintaining proportional relationships between processing times across production stages. Six cookie products (Maria, Sandwich, Whole Grain, Cookie, Water and Salt, and Wafer) were selected due to their similar raw-material compositions, which allows for coherent modeling and analysis of the costing system proposed to students. Product recipes were obtained from publicly available online sources, while additional information required for structuring the costing model was defined collaboratively with the course instructor. Developing the cost system required defining both raw material and packaging costs and production-related indirect costs. In PRODUBISC, this structure was established using the Standard Cost method (task 1) and the Production Effort Unit method (task 2). The SC calculation relied on information such as raw material required per portion (standard), consumption quantities and production volumes (Figure 1), along with the prices of the raw materials. The PEU method required additional data, including process descriptions, operational station photo-indexes, and the definition of the base product, all necessary to compute indirect costs according to the methodology.

COOKIE - Portion of 20 units		
Ingredients	Quantity	Unit
Wheat Flour	240	g
Sugar	160	g
Margarine	120	g
Eggs	10	unit
Vanilla extract	30	ml
Baking Soda	20	ml
Salt	10	g

COOKIE - production for the month: 20,000 units		
Ingredients	Consumption for the month	Unit
Wheat Flour	250,00	kg
Sugar	165,00	kg
Margarine	125,00	kg
Eggs	10.500	unit
Vanilla extract	32,25	l
Baking Soda	22,00	kg
Salt	11,50	kg

Figure 1. Quantity of raw materials required versus consumed by one of the products during the analysis period

4.2. Application

In the first phase (SC phase), during an in-person class session, the PRODUBISC Learning Factory was formally introduced to the students. Over approximately 20 minutes, the factory representatives, the course instructor, and the teaching assistant presented the company's main operational challenges and the expected outputs to be developed by the student "consultants." The 33 students enrolled in Cost Management Analysis (2025/1) then had an additional 20 minutes to work in groups, discuss the case, and formulate data requests necessary to address the proposed challenge. At the end of the session, the factory representatives provided each group with the datasets required for the subsequent analysis. Students were given one week to analyze the data set provided in the first session. During this period, they performed the required calculations, examined the company data, and prepared a presentation highlighting the key indicators related to PRODUBISC's raw material and packaging costs. In the second in-person class (second session), each group presented the results deemed most relevant to their peers and to the factory members. This meeting included detailed explanations of the cost-modeling procedures adopted by the teams and promoted extensive interaction among groups, fostering questions, complementary insights, and student-driven refinements to the analyses.

The second phase of the challenge (PEU phase) was conducted largely asynchronously, incorporating adjustments suggested by students and aligned with the course schedule defined by the instructor. The factory members introduced the new stage of the activity through a recorded video, initiating session 1. With extended time to request information and interact with the virtual company, the student groups communicated through dedicated discussion forums on Moodle Academic. As in the first phase, students later presented the dashboards they had developed, made with Power BI, and participated in discussions during session 2. By the end of this second phase, students were able to determine, for each product, the direct and indirect costs, thus obtaining the total manufacturing cost. Because the selling prices were available, they also calculated profitability indicators and proposed actions to improve the plant's overall performance. Because a managerial cost system has specific features defined by those who design it, some groups obtained slightly different total manufacturing costs for each type of cookie. During the classroom presentations, the groups, together with the professor, discussed the impact of these different modeling choices, revisiting theoretical concepts and best costing practices.

4.3. Evaluation

Students' perceptions regarding the implementation of PBL were collected through an evaluation form administered after each phase of the activity. In the first phase, the form remained available for 20 days, resulting in 28 responses out of 33 participants (84.8%). In the second phase, the form remained open for 5 days and received 22 responses from 31 students (71%). The instrument contained eleven questions, combining open-ended and multiple-choice items. The first question invited students to provide an overall assessment of their experience with PBL on a scale from 1 (very negative) to 5 (very positive). Results were strongly favorable: across both phases, 91.9% of respondents assigned scores of 4 or 5, indicating broad acceptance and a highly positive perception of the methodology (Figure 2).

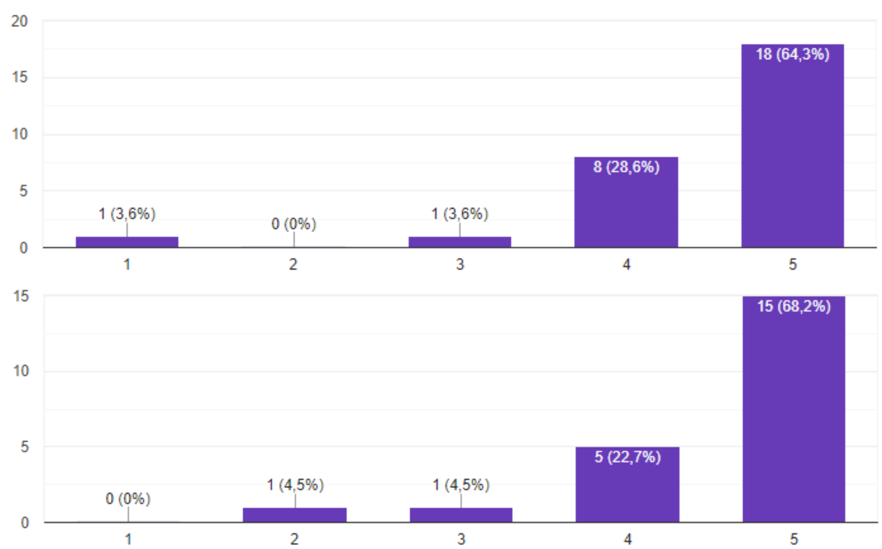

Figure 2. Responses regarding the general evaluation of the PBL experience.

Top: first phase. Bottom: second phase

Most students recognized a clear connection between the proposed challenges and the course content, reinforcing the relevance of the problems as meaningful drivers of learning. A small subset of respondents reported difficulty establishing this link, which may reflect challenges in contextualizing the scenario or relating it to specific concepts addressed in the course (Figure 3). These issues were not observed in the second phase, likely because students had more time to complete the activity and the problem was articulated with greater clarity.

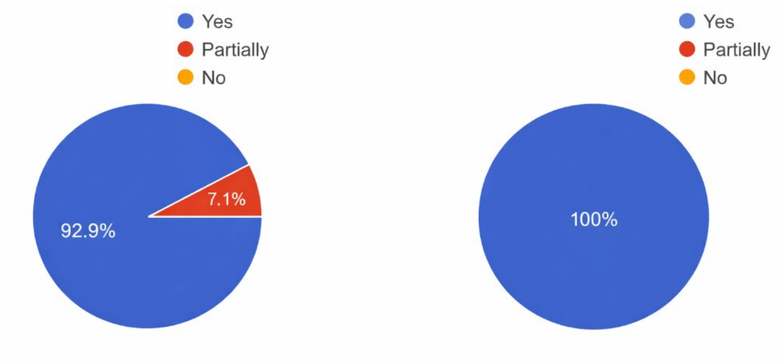

Figure 3. Responses regarding the perceived relationship between PBL challenges and course content
Left: first phase. Right: second phase

The third question examined whether the methodology met, exceeded, or fell short of students' expectations and invited justifications for their responses. In the first phase, 25% of students reported that the activity exceeded expectations, 64.3% indicated that it met expectations, and 10.7% stated that it fell short. Results from the second phase showed a slight improvement, with 36.4% reporting that the activity exceeded expectations, 54.5% that it met expectations, and 9.1% that it fell short. Students highlighted several positive aspects, particularly the opportunity to apply course content using realistic data and to construct customized indicators, which they reported enhanced conceptual understanding by moving beyond traditional theoretical exercises. One respondent noted that the activity "*simulated a real situation with more detail than usual classroom exercises*," promoting deeper mastery of the content. Constructive feedback emphasized uneven participation within groups, often concentrated on a few members, potential work overload, and the need for additional time or clearer guidance regarding the expected structure of the solution. The fourth question addressed whether the time allocated for group work was adequate. Most students considered the time sufficient (Figure 4). Even after the extension of deadlines in the second phase, a subset of students continued to perceive the available time as limited, a concern likely associated with the complexity of the challenge and the coordination required within teams.

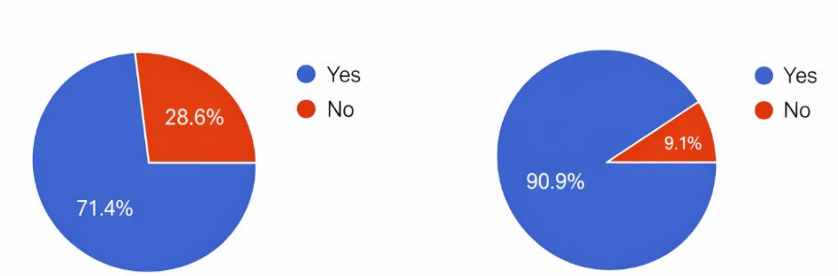

Figure 4. Responses regarding the sufficiency of time allocated for solving the PBL case
Left: first phase. Right: second phase

The fifth question examined students' perceptions of their learning throughout the tutoring process and collaborative problem solving. On average, 90.6% of respondents rated their learning experience as good or excellent. The second phase showed improved evaluations, likely due to more frequent interactions with the instructor and teaching assistant.

The timely clarification of questions during the activity also contributed to strengthening students' perception of learning (Figure 5).

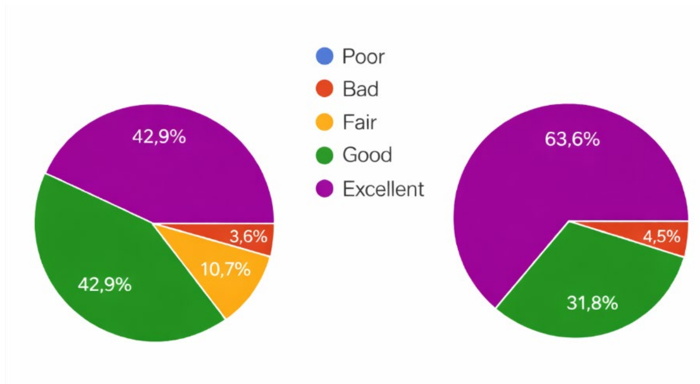

Figure 5. Responses regarding self-assessed learning and collaborative problem-solving in the PBL case
Left: first phase. Right: second phase

Students' perceptions of benefits and challenges emerged clearly in Questions 6 and 7. Reported benefits predominantly aligned with the pedagogical goals of PBL and included: practical application of course concepts; improved retention and deeper understanding of the material; development of interpersonal and professional skills; and increased autonomy and ownership over the learning process. As one student noted, *"Unlike typical Excel exercises that are already fully structured, the case offered contextualized and realistic data, making it clearer how the concepts apply in practice and facilitating the understanding of several topics."* Another emphasized the professional relevance of the method: *"Because it requires a more active stance, PBL not only reinforces content mastery but also illustrates how, as future engineers, we can use these tools in real projects, encouraging a results-oriented and professional mindset."* Challenges were also identified, falling into three main groups: (i) group size and coordination dynamics, (ii) time and workload management, and (iii) difficulties interpreting instructions or understanding the expected structure of the solution. As students highlighted, *"The main challenge was the limited time available, since solving a real problem requires greater organization and effort,"* and *"Adapting to a more active methodology, searching for information independently, and managing group work demand collaboration and structure."* Question 8 asked students to identify which competencies they developed through the activity. Results indicate strong contributions of PBL to both technical and behavioral skills, with particular emphasis on problem-solving and critical reasoning, competencies regularly associated with the theoretical foundations of PBL (Figure 6).

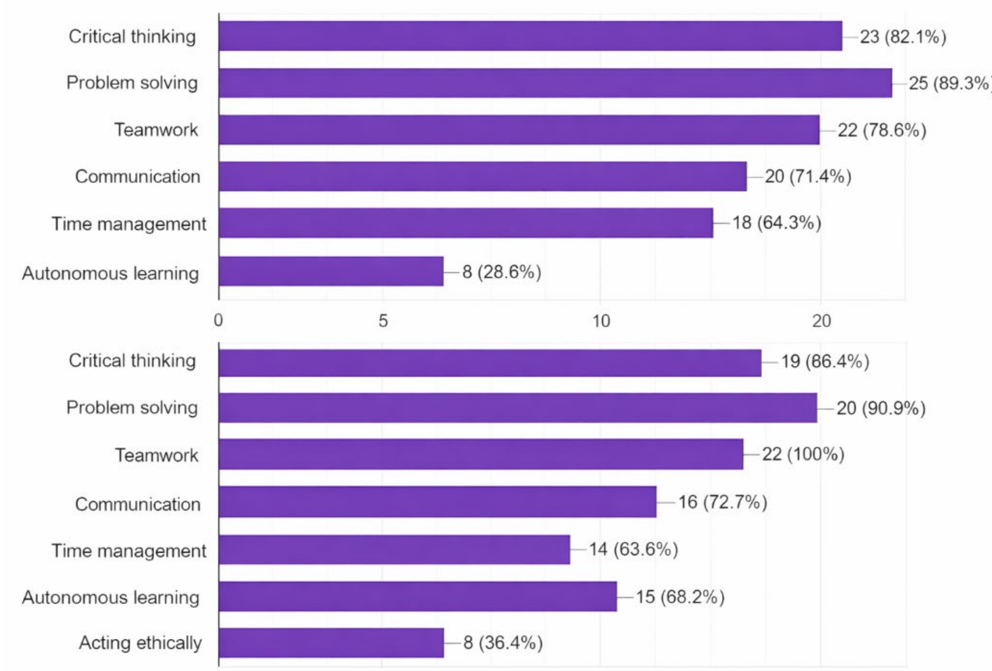

Figure 6. Responses regarding perceptions of skills developed through PBL

The top panel presents results from the first phase of implementation, and the bottom panel presents results from the second phase.

In Question 9, nearly all respondents indicated that PBL fostered a more proactive learning stance, demonstrating the method's capacity to stimulate curiosity, initiative, and autonomous engagement. Question 10 asked students to compare the effectiveness of PBL with traditional instruction. On average, 79.7% reported that PBL contributed more substantially to content assimilation and skill development. A small but consistent subset of five students preferred the traditional format in both phases. This comparison was feasible because traditional exercises had been assigned prior to the PBL presentations (Figure 7).

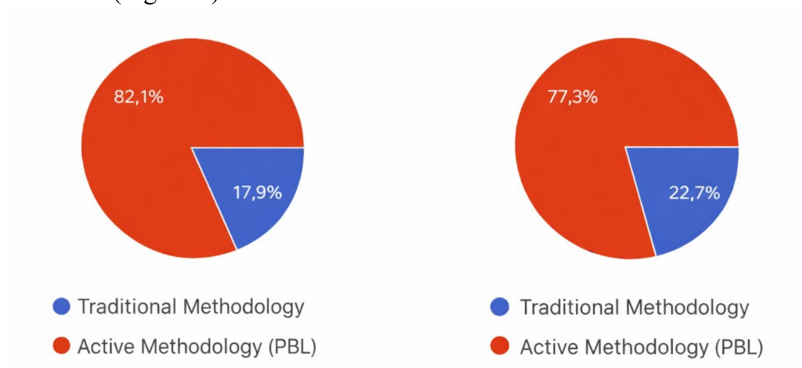

Figure 7. Responses regarding students' preferred methodology
Left: first phase. Right: second phase

This result reinforces students' preference for active learning, as many reported that the content became more meaningful when applied to a realistic scenario. The findings highlight the importance of instructional approaches that integrate conceptual understanding with practical, investigative, and collaborative learning. The open-ended responses also provided actionable suggestions for refining the PBL experience, which were grouped into four categories: adjustments in time and workload; improvements in presentation format; better alignment with curricular and assessment structures; and methodological refinements. Among the students who reported that PBL exceeded their expectations, 70% rated the methodology as "very positive" in phase 1, increasing to 100% in phase 2. Furthermore, between phases, students completed an individual exam on Standard Costing, and performance on the question directly related to the first PBL challenge was higher than in previous semesters — suggesting that PBL supported deeper content retention. Overall, the successful implementation of the planned stage, planning, application, and evaluation, demonstrated the feasibility and effectiveness of Problem-Based Learning in the Cost Management Analysis course. Although preliminary, the results indicate a positive impact on students' learning and perceptions, while also identifying opportunities for improvement in future iterations of the methodology.

Another positive aspect of using this PBL approach, based on the virtual factory, is that the instructor can modify the parameters of the industry and the products, generating new results. This enables greater engagement from students in subsequent semesters and prevents the modeling from simply being replicated, thereby creating new challenges and richer analytical opportunities.

The implementation of PBL also revealed challenges for both students and instructors. Students reported difficulties related to limited support, defining the scope of the problem, and organizing methodological steps, factors that may affect confidence and engagement, as corroborated by Araújo et al. (2025). Instructors, in turn, faced obstacles such as developing realistic cases that accurately reflect industry practices and managing the increased workload associated with continuous supervision and guidance. As highlighted by Figueiredo et al. (2020), these challenges reinforce the need for careful planning, institutional support, faculty preparation, and mechanisms that strengthen interaction with industry to ensure an effective and sustainable adoption of PBL.

5. Conclusion

This study implemented the PBL methodology in the Cost Management Analysis course of the Industrial Engineering program, assessing its effects on students' learning and perceptions. The initiative represents an important step toward updating the pedagogical approach of the course in alignment with the modernization goals of the PMG program. Across both phases of implementation, results were consistently positive. Students reported that PBL encouraged a more investigative and active engagement with the content, strengthening critical thinking and problem-solving skills. The challenge structured around the fictional learning factory effectively contextualized cost-system concepts, contributing to deeper conceptual understanding. Additionally, the development of the virtual factory infrastructure establishes a reusable foundation for future applications of the methodology. Some challenges were identified, including the need to adjust the academic timetable to accommodate the pacing required by PBL, to ensure timely access to structured company data, and to coordinate synchronous and asynchronous interactions. These aspects underscore the importance of refined planning for sustained integration of PBL into the course. Given that the discipline previously relied predominantly on traditional lecture-based instruction, the adoption of PBL demonstrated clear benefits for student engagement and content retention. The study's limitations relate mainly to its application in a single course offering and the potential for response bias in the survey data. Future work could involve expanding data collection, encouraging students to seek information beyond the materials provided, refining cost-system parameters, and enhancing company datasets to increase challenge complexity and realism. Considering the results and the broader efforts of the PMG program to foster innovative pedagogical practices, the implementation of PBL in Cost Management Analysis shows strong potential to become a reference within the Industrial Engineering curriculum. The structure developed in this study can be adapted for other courses, particularly those related to Production Planning and Control, given the flexibility and realism of the fictional factory model. This transferability reinforces the value of the learning environment created and supports the continued integration of active learning strategies across the program.

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