Implementation of problem-based learning in a production engineering graduation program in Brazil

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Abstract: This research aims at improving the professional competences and the fostering of soft skills in the Production Engineering graduate program at the Centro de Educação do Planalto Norte campus of Universidade do Estado de Santa Catarina, structuring the implementation of the active methodology Problem-Based Learning in the Production Systems II course. A systematic bibliographic review was conducted, comprising the period between 2015 and 2021, searching in SCOPUS and ScienceDirect databases, resulting in the systematization and analysis of 6169 papers, which substantiated the theoretical remarks of this study. The participants of the research composed a case study with the 11 students enrolled at the course during one semester of 2020. The questionnaire revealed that the students achieved a higher retention of the subject and felt a more direct connection between theory and practice than in other courses. Moreover, they reported feeling more engaged with the classes due to the Problem-Base Learning Methodology. The results of the Problem-Based Learning implementation were procured through a structured questionnaire and processed with Content Analysis. The research results allowed a conclusion that the proposed structure for Problem-Based Learning was effective concerning the steps taken and that the students successfully enhanced their problem-solving skills through soft skill fostering and reported a gain of professional competences by taking part in this research.

Keywords: problem-based learning, soft skills, production engineering.

Introduction

The role of intellectual capital and knowledge management in organizations has risen to a new position of relevance in managerial decisions and developing those skills in the new generation of professionals is of great importance, but it is also a great challenge. According to Sopa et. al (2020), there are two distinct types of knowledge: hard skills and soft skills. Hard skills consist of technical knowledge, related to mastery of science and technology, and produce something visible, easy to identify and assess, thus being easier to teach and evaluate. Soft skills on the other hand, are action and experience-rooted, closely connected to idealism, values, and emotions; they are personal and individual, not easy to manifest and be taught.

However, they are of the utmost importance to foment creativity and continuous learning, which are necessary for success in the work environment (Sopa et al., 2020; MacLeod and van der Veen, 2020; Erol et. al, 2016). The need for developing soft skills thus arises from the new focus employers are putting in this topic. Campos, Resende and Fagundes (2020) bring to light that employers are seeking engineers more capable in soft skills rather than hard skills, problem-solving being the most important one. Furthermore, problem-solving skills is key as it promotes other soft skills to flourish, e. g. communication. To keep developing that, students need to become self-learners, as in being capable of understanding new concepts and barriers by themselves, and active methodologies, such as Problem-Based Learning (PBL), promote a huge gain in this area (Chao, Chen and Chuang, 2015).

Building up on the challenge of teaching soft skills, Tortorella and Cauchik-Miguel (2017) state that the lack of a context upon which students can build their knowledge and, mainly, transfer it to the workplace and its unique settings, presents a barrier for both educators and students. Moreover, the utilization of a single teaching method, especially being that a passive method, contributes to deepen that challenge. Therefore, this calls for a change on the way we teach and learn in engineering, bringing the workplace and the academic environment closer, adding practical expertise to the graduates through a paradigm shift from passive to active learning (Hernáiz-Perez et al., 2021); and that is where Problem-based Learning comes in. The interaction with other people promoted by PBL allows students to perceive the need to develop soft skills so their discussions and solutions can advance and does it by shifting the priority from a discipline's content to solving the problem, showing that there is a greater depth to real-world situations than using the proper set of equations (MacLeod and van der Veen, 2020).

Although there are many obstacles to developing those desirable skills, success in improving education through practical teaching approaches has already been achieved within the engineering environment. In Brazil, there is the case of the Project-Based Learning curriculum applied at Universidade de Brasília, which is rated at 4.8 out of 5 points in Brazil's Exame Nacional de Desempenho dos Estudantes, a nationwide evaluation system for higher education courses, as shown by Monteiro et al. (2017). There is also the case presented by Tortorella and Cauchick-Miguel (2017), who applied Problem-Based Learning into a lean manufacturing course at Universidade Federal de Santa Catarina, combining traditional approaches with PBL to develop a wide range of skills. Worldwide there are more examples: Barak and Yuan (2021) showed the correlation between a project-based learning approach (which only differs from problem-based learning on structuring the problem) and innovative thinking; MacLeod and van der Veen (2020) created an interdisciplinary project-based learning approach to solve traffic issues in a hospital using stochastic modelling, promoting student learning by gathering Civil Engineering, Industrial & Engineering Management and Applied Mathematics students to work together to solve the proposed problem.

Considering the challenges and cases presented, this research demonstrates the application of Problem-Based Learning in a Production

Systems class at Universidade do Estado de Santa Catarina's Centro de Educação do Planalto Norte (UDESC/CEPLAN), in Brazil, within the Production Engineering graduation program. The authors observed empirically a gap in the curriculum at UDESC/CEPLAN regarding the practical approach to teaching and readiness of the graduates to move from academia to industry and selected the Problem-Based Learning methodology as a possible solution, as it focuses on problem-solving skills, which are the most important soft skill group for modern employers. Another challenge faced in this research is the application of active methodologies in the context of remote classes, as the study was conducted during the COVID-19 pandemic, with restrictions that prohibited students, professors, and university employees to attend classes at the university. This factor emerged as a barrier to student engagement in classes, as observed by the authors. From these perceptions, the research was structured to answer the question of how to implement PBL in a Production Engineering graduation program aiming at fostering soft skills in the educational process, comprising three steps: implement PBL in the selected course; evaluate PBL's impact on soft skill fostering and evaluate PBL's impact on student engagement.

The structure by which the remainder of this study is divided consists of five sections: section 1 consists of this introduction and contextualization of the study; section 2 contains an aggregate review of existing literature on competences and Problem-Based Learning; section 3 presents the methodological remarks for the systematic literature review and for the field research; section 4 explains and discusses the results found and section 5 expresses concluding remarks and future research opportunities.

Literature review

Competences

Firstly, it is important to differentiate two distinct concepts that are frequently used as synonyms: skills and competences. Skills are instrumental, on a micro scale; competences, on the other hand, are a macro concept, regarding the application of skills along with cognitive capabilities to complete a task (Campos, 2019).

Competences, in a higher education context, comprise the development in students of both technical instruments, as in cognitive processes of thought and learning, and interpersonal skills, all necessary in a work environment, according to Soares and Del Prette (2015). For Pittich, Tenberg and Lensing (2020), competences are manifested in a disposition to act independently, being proactive. Combining these two aspects of the competence concept, the development of both thinking and social skills, and proactivity, it is possible to state that a competent person must be able not to only understand theory, but also to apply it. Competent persons do not reproduce a method, they comprehend the situation and act on their own will and attitude, relating to the KSA tree, which comprises the three aspects involved in competence development: knowledge, skills, and attitude (Soares and Del Prette, 2015; Pittich; Tenberg and Lensing, 2020; Campos, 2019). Figure 1 shows the KSA tree.

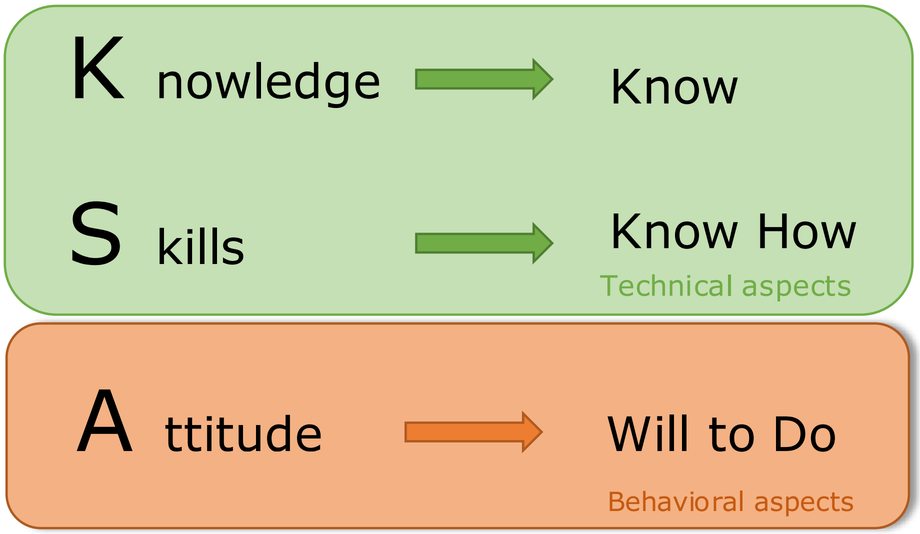

Figure 1 – KSA Tree. Source: Adapted form Prates (2014).

Thus, this requires two types of learning: the comprehension-based learning, which makes knowledge transferrable to teach the theory, and action-based learning, which makes it applicable. The combination of action-based learning and comprehension-based learning is what creates competences that effectively enhance a professional's capabilities, as they are trained in both theoretical and practical exercises, and only succeeds if both are conducted together (Pittich, Tenberg and Lensing, 2020). Thus, PBL arises to address the combination of comprehension-based learning through self-studying and action-based learning through teamwork on solving a real-world problem.

Problem-based learning

The Problem-Based Learning methodology consists in presenting students a poorly structured real-world problem, so they need to understand the problem, structure the learning objectives, and develop a feasible solution for the proposed problem (Monteiro et al, 2017). Being an active teaching methodology, Problem-Based Learning directly interacts with the flipped classroom model, which consists in instructing students to study the proposed content before class, allowing for the time spent in class to be used for discussions and to implement diverse methodologies, such as Problem-Based Learning itself (Chao et al., 2015; Hernáiz-Perez et al., 2021). This model brings some advantages to the learning process, remarkably related to student engagement and self-learning development by shifting from a passive role for an active role for students in their learning process (Al-Samarraie; Shamsuddin and Alzahrani, 2020).

According to Monteiro et al. (2017), the use of a Problem-Based Learning approach to higher education teaching promotes three advantages: it facilitates the development of both hard and soft skills, meaning both technical knowledge and personal-contextual skills; it also brings the student to a more active perspective of the learning process; furthermore, there is a bigger sense of responsibility involved for the student, as the learning process is now student-centered.

These characteristics are alike to the objectives of the Science, Technology and Society (STS) approach, although PBL and STS differ in two aspects: in the way they are applied, and in what they aim to achieve. As shown by Aikenhead (2011), STS derives from an attempt to correct three failures of the traditional science teaching model: low student enrolment, the conveyance of myths to the students and the failure to provide meaning for the science content outside of school; thus, STS aims to provide meaningful teaching of science skills to students. This is the difference in scope: PBL aims to develop soft skills, and STS aims at science skills. The difference in application is that, while applying PBL affects directly on the way the educator conducts each class, STS is a broader approach, changing the curriculum structure to contemplate the Science, Technology and Society concepts within the whole program, enabling students to perceive the connections between these concepts, which promotes effective learning of science skills (Aikenhead, 2011).

There are several reasons why the Problem-Based Learning methodology is interesting to engineering courses, some of them being the need to graduate engineers who can face the new technological challenges brought about with Industry 4.0, being flexible and agile to quickly adapt to the changes and dealing with increasingly complex organizations (Monteiro et al., 2017; Sopa et al., 2020; Erol et al., 2016); the need to create a connection between academic and real-world applications of subjects studied within the course, contributing to the formation of engineers capable of tackling real-life problems in an industrial context; the increased development of soft skills, such as teamwork, communication, and leadership (Tortorella and Cauchik-Miguel, 2017; Mirkouei et al., 2016); and the higher student motivation achieved with the shift from theoretical studying to practical applications of the concepts (Monteiro et al., 2017; Tortorella and Cauchik-Miguel, 2017). Teamwork, especially, as part of cooperative learning, has a positive effect on developing scientific skills such as observing, inferring, classifying, communicating, measuring, and predicting, which can enhance students' problem-solving capabilities, as they develop logical and systematic thinking (Prayitno et al., 2017).

To address the implementation issue, Abdalla and Gaffar (2011) divided the Problem-Based Learning methodology in seven steps. The first step is to "clarify the setting", or the context where the problem is structured. That means everyone needs to understand the terms and notions and agree on what they mean, so the students know what they are working with. The second step is the "definition of the problem", stating clearly what are the main problem and the sub-problems present in the situation and choosing which ones the group is going to work on. Step three consists in analyzing the case and brainstorming ideas for the solution. In the fourth step, the group eliminates irrelevant points and brings a systemic view of the problem, which allows for developing the fifth step: "definition of learning objectives". With what the students need to study defined in step five, step 6 is a time of self-study when each of the students learns the topics gathered in the previous step. Finally, step 7 consists of meetings to discuss what was learned and solve the problem.

Methodology

The research methodology was divided in three sections: the literature study method (section 3.1) explains the process utilized to search and select relevant literature, which guides potential topics of interest, research gaps and provides a number of successful cases. The field research methodology (section 3.2) presents the steps taken to implement Problem-Based Learning and analyze its results. Finally, section 3.3 discloses the Content Analysis method, selected to treat the data amassed in the field research.

Literature review methodology

In the 2010-decade, scientific research dramatically increased in number of publications, making it difficult for researchers to extensively keep track of existing knowledge. Therefore, the use a systematic method of reviewing literature is valuable in its effects (Zupic and Cater, 2015). For this research, the selected method was a systematic bibliographical review, followed by the application of Methodi Ordinatio, which will be explained further ahead.

The first step of the systematic bibliographical review was defining the keywords to be used for the search. The research question was divided into three branches, composing the three aspects involved in the field research: the teaching branch, the skills branch, and the engineering branch, as shown in Figure 2. The keywords were chosen looking to comprehend in literature all the aspects that compose the development of this study: Engineering teaching, which comprises the methods and objectives of teaching existing within the Engineering environment; Problem-Based Learning corresponds to the understanding of the applied methodology; Skills relate to the fostering of soft skills, one of the research goals; Production Engineering is the field of the graduation program where the research was conducted; and Production Systems compose the technical content of the course in which Problem-Based Learning was applied.

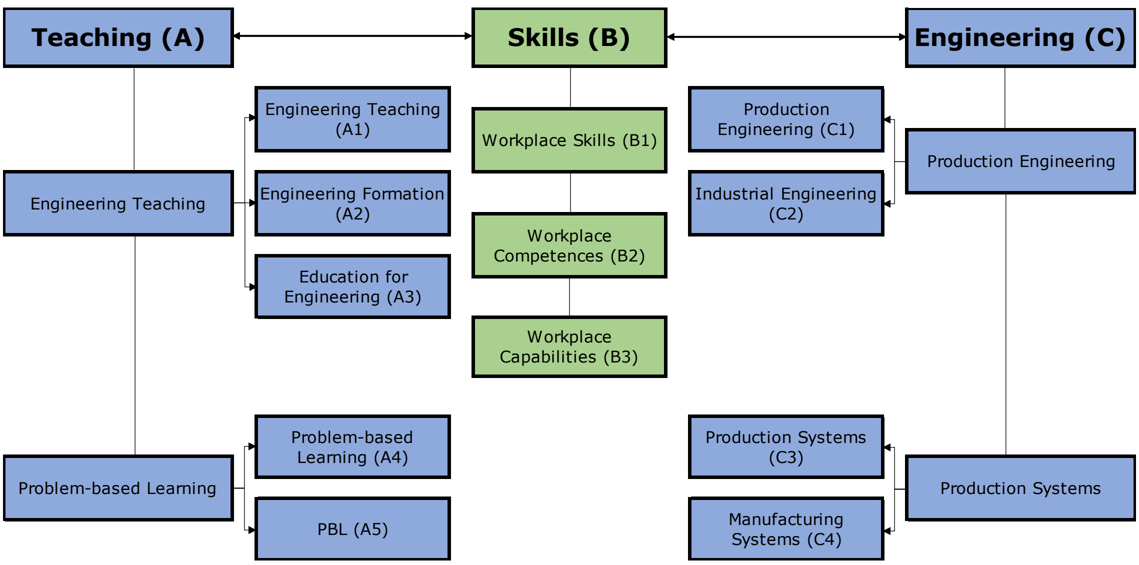

Figure 2 – Keyword branches for literature search.

The keywords were defined by a set of combinations between the three branches from Figure 2, in the following manner: A1B1C1, A1B1C2, A1B1C3, A1B1C4, A1B2C1, A1B2C2, A1B2C3, A1B2C4, A1B3C1, A1B3C2, A1B3C3, A1B3C4, A2B1C1, A2B1C2, A2B1C3, A2B1C4, A2B2C1, A2B2C2, A2B2C3, A2B2C4, A2B3C1, A2B3C2, A2B3C3, A2B3C4, A3B1C1, A3B1C2, A3B1C3, A3B1C4, A3B2C1, A3B2C2, A3B2C3, A3B2C4, A3B3C1, A3B3C2, A3B3C3, A3B3C4, A4B1C1, A4B1C2, A4B1C3, A4B1C4, A4B2C1, A4B2C2, A4B2C3, A4B2C4, A4B3C1, A4B3C2, A4B3C3, A4B3C4, A5B1C1, A5B1C2, A5B1C3, A5B1C4, A5B2C1, A5B2C2, A5B2C3, A5B2C4, A5B3C1, A5B3C2, A5B3C3, A5B3C4. The main concepts within each branch were selected, and their synonyms gathered and combined to generate the final keywords. Table 1 presents the 26 final keywords.

Keywords
Engineering teaching AND Workplace skills AND "Production Engineering"
Engineering teaching AND Workplace skills AND "Industrial Engineering"
Engineering teaching AND Workplace competences AND "Production Engineering"
Engineering teaching AND Workplace competences AND "Industrial Engineering"
Engineering teaching AND Workplace capabilit* AND "Production Engineering"
Engineering teaching AND Workplace capabilit* AND "Industrial Engineering"
Engineering formation AND Workplace skills AND "Production Engineering"
Engineering formation AND Workplace skills AND "Industrial Engineering"
Engineering formation AND Workplace competences AND "Production Engineering"
Engineering formation AND Workplace competences AND "Industrial Engineering"
Engineering formation AND Workplace capabilit* AND "Production Engineering"
Engineering formation AND Workplace capabilit* AND "Industrial Engineering"
Education for Engineering AND Workplace skills AND "Production Engineering"
Education for Engineering AND Workplace skills AND "Industrial Engineering"
Education for Engineering AND Workplace competences AND "Production Engineering"
Education for Engineering AND Workplace competences AND "Industrial Engineering"
Education for Engineering AND Workplace capabilit* AND "Production Engineering"
Education for Engineering AND Workplace capabilit* AND "Industrial Engineering"
"Problem-based Learning" AND "Production Engineering"
"Problem-based Learning" AND "Industrial Engineering"
"Problem-based Learning" AND "Production systems"
"Problem-based Learning" AND "Manufacturing systems"
"PBL" AND "Production Engineering"
"PBL" AND "Industrial Engineering"
"PBL" AND "Production systems"
"PBL" AND "Manufacturing systems"

Table 1 – Keyword combinations utilized in the research.

The keywords in Table 1 are the results of all selected combinations between the three branches, with two groups of exceptions: The combinations between A4 (PBL) and A5 (Problem-Based Learning) with the skills branch were discarded because the PBL methodology brings within its objectives the development of workplace-related skills; and the combinations of A1 (Engineering teaching), A2 (Engineering formation) and A3 (education for Engineering) with C3 (production systems) and C4 (manufacturing systems) were discarded due to the resulting papers showing a focus on hard skills, which does not align with this research.

The choice of the final group of papers to be read was conducted through the Methodi Ordinatio method, developed by Pagani, Kovaleski and Resende (2015). This consists of a mathematical expression that factors the number of citations and the publication year of the paper along with the impact factor of the journal in which it was published and a priority level defined by the researcher, providing an objective scale of importance to select the portion of literature that is most relevant to the research goal. The result is called Index Ordinatio and is calculated according to equation (1):

$$In = \left(\frac{IF}{1000}\right) + \alpha * [10 - (ResYear - PubYear)] + \sum Citations \qquad (1)$$

in which *In* stands for the Index Ordinatio value, *IF* is the journal impact factor, gathered from ClarivateAnalytics Journal Citation Reports®, *α* is the priority level, which is defined by the researcher according to the relative centrality of each group of results to the research (for this research, value 10 was assigned to keywords that contain PBL or Problem-Based Learning, as this is the main concept, and value 9 was assigned to all the others), *ResYear* is the year when the search was conducted, *PubYear* is the year when the paper was published and $\sum Citations$ is the number of citations for that paper, collected from Google Scholar®, as it was the source utilized by Pagani, Kovaleski and Resende (2015) when developing Methodi Ordinatio. It is important to notice that some inputs directly influence the filters which were applied to the database search results, namely the impact factor, which is evaluated only for papers published in peer reviewed journals; thus, it is necessary to discard all results which are not journal articles from the database search.

This was done for each of the 490 papers left after applying the filters, and the ones with an Index Ordinatio of 100 points or more were selected, resulting in a total of 47 papers, 3 of them deemed valuable to the research based on a frisking after reading the abstract. Figure 3 presents the filtering steps. It is important to note that, even after the application of these filters, there were still papers which did not align with the desired content for the research scope, especially those focusing on e-learning, which is why not all 47 resulting papers form Methodi Ordinatio were cited.

Field research methodology

The study was conducted at Universidade do Estado de Santa Catarina, in the Centro de Educação do Planalto Norte campus, in São Bento do Sul, Brazil. The graduation program that received the study was the Production Engineering program, and the methodology was applied at the Production Systems II course, which comprises supply chain management, production line efficiency and lean manufacturing as its main subjects. This course was deemed fit for the study because of its direct application in the industrial environment. At the time of the research, 11 students were enrolled at this course, and all agreed to participate in the research.

The Problem-Based Learning methodology starts by gathering data and defining the problem which will be presented to the students. For this research, a local business, a furniture manufacturer, was contacted and presented data for use in the project. The data consisted of OEE indicators, 5S auditing reports, product’s bill of materials and production scripts, and plant layout. The problem applied was a low productivity from a painting line, manifested in high lead times for that section, so the students were asked to bring forth possible improvements to line productivity, eliminating wastes and reducing the movements.

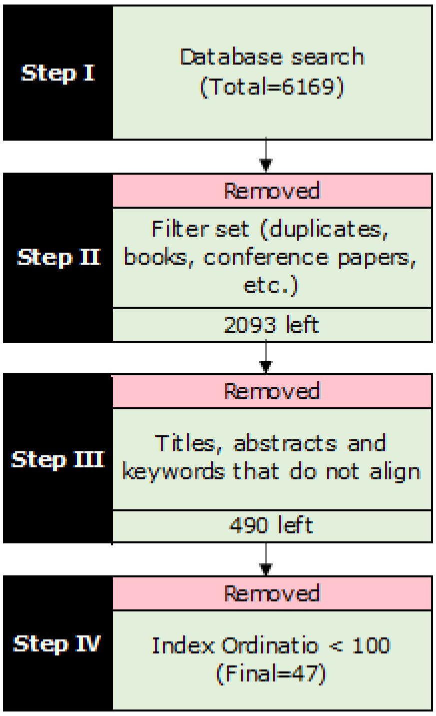

Figure 3 – Filters applied to select paper references.

The methodology was structured to be administered in a one-month period, consisting of 10 classes, as shown in Figure 4. The organization of the classes considered two aspects: the seven steps of Problem-Based Learning, as defined by Abdalla and Gaffar (2011), and the remote teaching model adopted at the selected university due to the COVID-19 pandemic. This remote teaching model consisted in two types of online classes: synchronous and asynchronous. Synchronous classes are videoconference calls in which the professor teaches a usual class, with the professors themselves and all the students attending the call at the same time. Those are shown in yellow in Figure 4. Asynchronous classes are recorded videos or proposed exercises meant for the students to work without the presence of the professor. Those are shown in blue in Figure 4. This allowed for some steps that do not require as much influence of the educator to be placed outside of class time, namely step 3 (brainstorming) and step 6 (self-study).

The evaluation of the results utilized a structured questionnaire, based on the specific goals of the research, designed to collect and understand students' impressions of their own learning and development after working with Problem-Based Learning. This method was chosen to evaluate the effects of Problem-Based Learning in soft skills, which, due to their personal nature, hamper the effective application of a quantitative treatment method. Therefore, the questionnaire was structured to allow subjective and personal answers, aligning with the innate intimacy of soft skills. This questionnaire was composed of seven questions, five requiring descriptive answers, as described in Table 3. Responses were obtained from eight students, which will be referred to as S1, S2, S3, S4, S5, S6, S7 and S8 to preserve their identities.

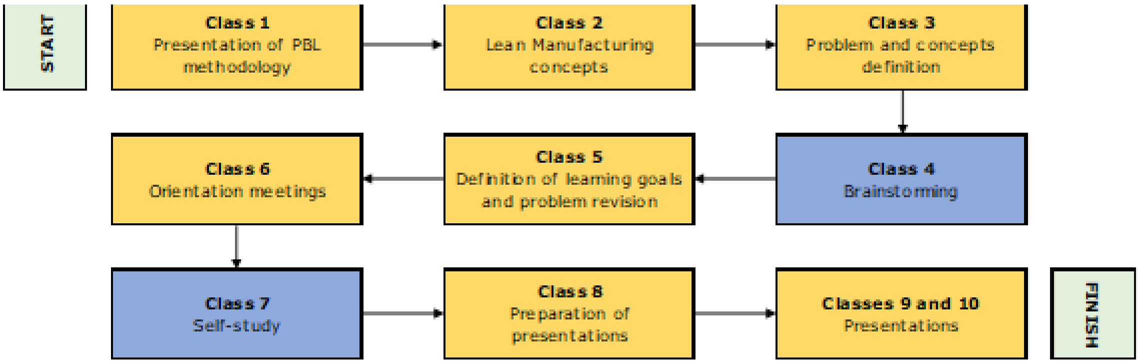

Figure 4 – Proposed structure for Problem-Based Learning implementation. Source: Based on Abdalla and Gaffar (2011).

Question		Answer
Q1	Judge your engagement in online classes due to the COVID-19 pandemic in comparison with previous semesters.	Substantially increased Partially increased Unchanged Partially decreased Severely decreased
Q2	Did your engagement in the classes with this active methodology change in comparison to the traditional methodology? How? Comment.	Descriptive
Q3	Comparing to the traditional methods, what is your perception regarding your comprehension of the subject discussed in this active methodology?	Descriptive
Q4	Was the available time adequate?	Yes No, more time was necessary No, less time would be enough
Q5	Did you like this experience? Why?	Descriptive
Q6	Did you feel worried/insecure about studying with this methodology? Comment.	Descriptive
Q7	Do you have any suggestions?	Descriptive

Table 3 – Questionnaire applied with the participant students.

Another questionnaire was applied with the professor responsible for the course, obtaining feedback from the educator, evaluating the effectiveness of the methodology. The structure of the questionnaire is described in Table 4.

Data treatment

The amassed data was treated through Content Analysis, briefly defined by Bardin (2001) as an agglomerate of techniques to analyze communications, aiming to decode the messages and unveil the meaning behind what is written.

The Content Analysis method is divided into three major steps: the pre-analysis, the material exploration and the treatment of results and interpretations. These steps and the actions within them are shown in Figure 5. In the pre-analysis step, the goals of the questionnaire were defined, working as guidelines to the definition of the questions. In the material exploration step, the answers were collected and skimmed, outlining major keywords. In the treatment and interpretation step, the organized data was analyzed, and inferential conclusions were made regarding the object: students' own evaluation of their learning process.

	Question	**Answer**
Q1	Judge student engagement in online classes due to the COVID-19 pandemic in comparison with previous semesters.	Substantially increased Partially increased Unchanged Partially decreased Severely decreased
Q2	Did you perceive any changes in student engagement in the classes with this active methodology in comparison to the traditional methodology? How? Comment.	Descriptive
Q3	Comparing to the traditional methods, what is your perception regarding student comprehension of the subject discussed in this active methodology?	Descriptive
Q4	Was the available time adequate?	Yes No, more time was necessary No, less time would be enough
Q5	Did you like this experience? Why?	Descriptive
Q6	Did you feel worried/insecure about teaching with this methodology? Comment.	Descriptive
Q7	Do you have any suggestions?	Descriptive

Table 4 – Questionnaire applied with the responsible professor.

The pre-analysis in this research initiated with the systematic bibliographical review, aiming to collect relevant literature and build a conceptual ground regarding soft skills and Problem-Based Learning and also regarding the state of the art in these topics. Based on the literature study, research question and objectives were defined, which guided the definition of the methods used to collect and analyze data. The material exploration phase consisted in the application of the questionnaire with professor and students.

For the statistical operations step, henceforth named descriptive statistics, two analyses were conducted: the selection of keywords in the students' responses that alluded to soft skills or Problem-Based Learning objectives, therefore showing that students perceived the mentioned concepts, with support of literature findings as displayed in Table 5, and the frequency analysis of these concepts, referring to identifying the number of citations for each concept. In the synthesis of and selection of results step, extracts of the descriptive answers were selected to show evidence of the results found in the statistical study. Finally, along with literature, inferences were made from the results so that interpretations were possible. The data considered for these studies derives from the students' responses only, due to the personal character of the questions.

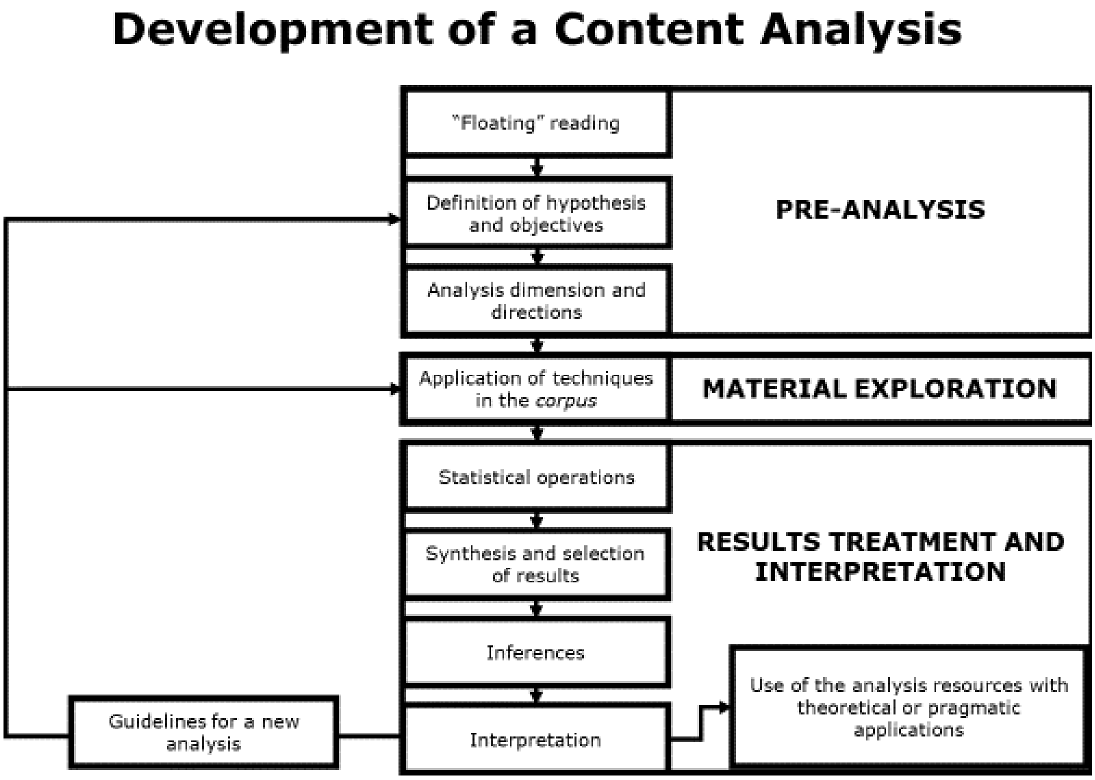

Figure 5. Steps of Content Analysis. Source: Based on Bardin (2001).

Results and discussions

In this section, the results obtained with the questionnaire responses are presented, starting with a reflection regarding the proposed structure for Problem-Based Learning implementation, followed by the display of the Content Analysis results, deepening the study on the benefits brought about by the methodology.

PBL implementation

The effectiveness of the proposed Problem-Based Learning structure was evaluated in the questionnaire through three specific questions, namely Q4, Q6 and Q7. Question Q4 asked the students about the time available for developing their solutions, question Q6 investigated the presence of insecurity related to PBL and question Q7 gave respondents a section to present suggestions.

The answers to question Q4 "The available time was adequate?" were divided, 50% of the students answering that it was adequate, and the other 50% answering that it was not enough, and more time should be planned. However, some of the answers to question Q7 show a trend, as student S2 said "Give more time […]", and student S3 answered that "Plan more time […]" would be important. Also, the professor's answer follows this inclination, affirming that more time was necessary.

Question Q6 "Did you feel worried/insecure about studying with this methodology? Comment" sought to evaluate the impact of allocating class time to present the methodology and to teach a common basis of concepts before starting to apply the seven steps of Problem-Based Learning. A positive impact was shown, given that 63% of the students did not manifest worry/insecurity feelings regarding the development of the methodology. An explanation for this correlation can be observed in the following excerpt from student S1's reply:

> Only when the methodology was presented. I believe that this insecurity was derived from the unfamiliarity with PBL. However, as the classes elapsed, with the increased knowledge of the objectives and expected results from the application of this methodology, the insecurity faded […] (S1)

Concept	**Authors**
	PBL
Engagement	Barak & Yuan (2021); Al-Samarraie, Shamsuddin & Alzahrani (2019); Monteiro et. al (2017); Tortorella & Cauchick-Miguel (2017); Hernáiz-Pérez (2021);
Competence development	Soares & Del Prette (2015); Barak & Yuan (2021); Monteiro et. al (2017);
Relevance of soft skills	Monteiro et. al (2017); Campos et. al (2020);
Knowledge contextualization	Monteiro et. al (2017); Tortorella & Cauchick-Miguel (2017); Hernáiz-Pérez et. al (2021); MacLeod & van der Veen (2020); Pittich, Tenberg & Lensing (2019);
Theory-practice connection	Al-Samarraie, Shamsuddin & Alzahrani (2019); Monteiro et. al (2017); Tortorella & Cauchick-Miguel (2017); Prayitno et. al (2017); Hernáiz-Pérez et. al (2021); MacLeod & van der Veen (2020);
Active role of the student	Al-Samarraie, Shamsuddin & Alzahrani (2019);
Interaction with the educator	Al-Samarraie, Shamsuddin & Alzahrani (2019);
	Soft Skills
Problem-solving	Soares & Del Prette (2015); Al-Samarraie, Shamsuddin & Alzahrani (2019); Monteiro et. al (2017); Tortorella & Cauchick-Miguel (2017); Campos et. al (2020); Prayitno et. al (2017); MacLeod & van der Veen (2020);
Creativity	Barak & Yuan (2021); Monteiro et. al (2017); Campos et. al (2020); MacLeod & van der Veen (2020); Sawyer (2018);
Teamwork	Barak & Yuan (2021); Mirkouei et. al (2016); Monteiro et. al (2017); Tortorella & Cauchick-Miguel (2017); Campos et. al (2020); Pittich, Tenberg & Lensing (2019);
Communication	Monteiro et. al (2017); Tortorella & Cauchick-Miguel (2017); Campos et. al (2020); MacLeod & van der Veen (2020); Pittich, Tenberg & Lensing (2019);
Critical thinking	Monteiro et. al (2017); Campos et. al (2020); Prayitno et. al (2017); Hernáiz-Pérez et. al (2021);
Multidisciplinarity	Monteiro et. al (2017); MacLeod & van der Veen (2020);

Table 5 – Bibliometric analysis of relevant topics for this study.

This aspect presented by the student shows that the novelty of Problem-Based Learning, for a given group of students, may bring concerns, nonetheless, familiarization with the process can soften the initial impact, reinforcing the contribution and validating the inclusion of a class to present the methodology, which allows the students to question and debate with the professor the organization of the method.

Content analysis application: Descriptive statistics

After the collection of responses from the questionnaire, a frisking of the documents was conducted, aiming to identify the main tendencies and observe respondents' suggestions and contributions. Then, a more profound reading of each answer highlighted expressions within those answers that relate to the concepts shown in Table 5. Table 6 presents the expressions mentioned by the respondents and the correspondent concepts, according to the literature analysis.

Concept	Identified expressions
Critical thinking	Incentive to question
Communication	Debate; discussion; communication; makes interacting easier
Teamwork	Contact with the group
Creativity	Creative thinking
Effective learning	Consolidate knowledge; I was able to comprehend more of the subject; I learned more; greater knowledge of the subject; better retention of the subject
Theory-practice connection	The student acquires a more practical knowledge; made it possible to understand how things work in practice; easier to do in practice; experience; helps to envision day-to-day activities
Multidisciplinarity	Multidisciplinarity
Curiosity	Curiosity
Engagement	Engagement; it is possible to engage more with others; incites students to ask for help; I can pay more attention to class
Active role of the student	The student seeks the knowledge; incites the student to seek knowledge
Diversity of ideas	Multiple perspectives; freedom to develop; multiple opinions; diverse points of view
Interaction with the educator	It is possible to engage more with the professor

Table 6 – Relations between the expressions identified in the responses and the listed concepts.

It is noticeable that the students themselves manifested a perception of both Problem-Based Learning objectives and soft skills fostering, as stated in Table 6. Noticeably, there was a perception regarding the gaps observed by the authors, comprising soft skill fostering as a way to enhance work-related competences, connecting academic and professional environments, and the engagement decrease during the COVID-19 pandemic.

The frequency analysis traversed two aspects: evaluate the global frequency (how many times each concept was cited among all answers) and the local frequency (how many times each concept was cited within the answers to a single question). Table 7 presents the results of concepts' global frequency.

The global frequency allows the understanding of which concepts were more easily perceived by the students, indicating that such aspects have been better developed within the methodology. The most cited concept, as shown in Table 7, was effective learning, which concurs with Problem-Based Learning's objectives, bringing about knowledge contextualization and action-based learning to enable the construction of significance to the subject. The second most cited concept, the connection between theory and practice, shows success in filling the gap between the academic environment (theory) and the professional environment (practice). The engagement concept was also cited various times, showing that the methodology obtained success in improving class participation.

Concept	**Responses that cited this concept**	**Number of citations per response**	**Total**
Critical thinking	S8	1	1
Communication	S1	2	5
	S3	1	
	S4	1	
	S5	1	
Teamwork	S3	1	1
Creativity	S6	1	1
Effective learning	S1	1	7
	S2	1	
	S3	1	
	S4	2	
	S5	1	
	S8	1	
Theory-practice conection	S1	1	6
	S2	2	
	S5	2	
	S8	1	
Multidisciplinarity	S1	1	1
Curiosity	S1	1	1
Engagement	S1	1	4
	S4	2	
	S7	1	
Active role of the student	S1	1	2
	S6	1	
Diversity of ideias	S2	1	5
	S6	1	
	S7	1	
	S8	2	
Interaction with the educator	S4	1	1

Table 7 – Global frequency of the identified concepts in the students' responses.

The local frequency allows the visualization of the relationships between the concepts cited in the answers and the goal of the question being analyzed, thus, this step was applied only to questions Q2, Q3 and Q5, which directly relate to the specific goals of this research. Figure 6 presents the frequency analysis for question Q2 "Your engagement in the classes with this active methodology changed in comparison to the traditional methodology? How? Comment."

This question, which is directly connected to the objective of increasing student engagement, allows to observe, as displayed in Figure 6, that there was a gain in engagement and evokes possible reasons why, notably the theory-practice connection and communication, being these three concepts correspondent to 50% of the overall citations. This is an important factor, given that the answers to question Q1 "Judge your engagement in online classes due to the COVID-19 pandemic in comparison with previous semesters", as shown in Figure 7, confirmed the authors' observation about the negative impact of remote classes in student engagement.

Students' answers, observed in Figure 8, show that effective learning was directly perceived by 50% of the respondents, also being well above the sample mode of 1 citation, indicating that this aspect was evident to the respondents, and thus that Problem-Based Learning was effective in bringing about more significant knowledge to students. As in question Q2, it is also possible to postulate that the other cited concepts favor this improve in learning. These findings align with the case studied by Monteiro et al. (2017), who affirm that adopting Project-Based Learning (which differs form Problem-Based Learning only in the structure of the problem) was a key factor to achieve success in developing improved learning, being the success of that case evident in the evaluation of the graduation program in question with 4.8 out of 5 in Brazilian test Exame Nacional de Desempenho dos Estudantes.

Question Q5 "Did you like this experience? Why?" sought to understand if students thought that working with PBL as a positive experience, and if so, which aspects sparked their interest, evidencing topics that can be focused when implementing Problem-Based Learning. All the respondents answered that they liked working with Problem-Based Learning, and Figure 9 shows the cited concepts.

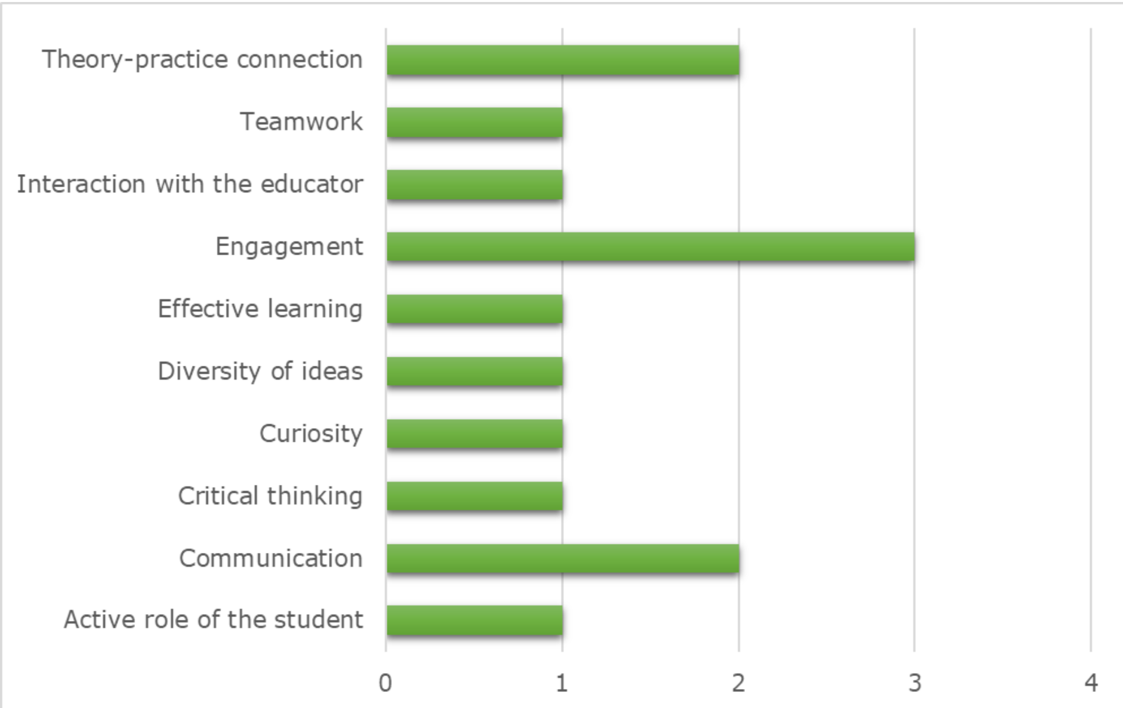

Figure 6 – Local frequency of the concepts identified in the answers to question Q2 "Your engagement in the classes with this active methodology changed in comparison to the traditional methodology? How? Comment.".

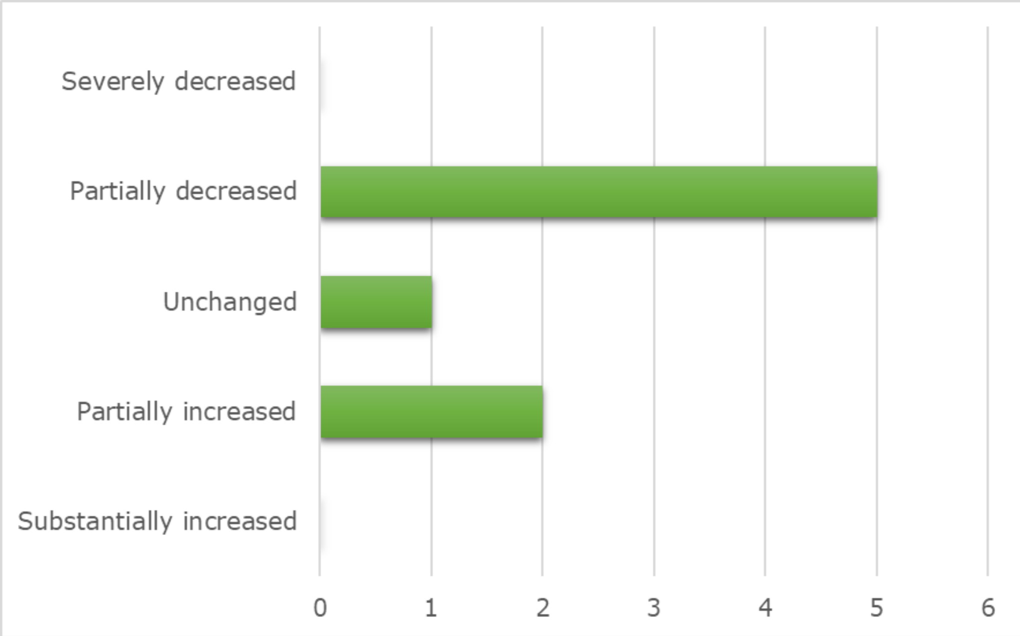

Figure 7 – Answers to question Q1 "Judge your engagement in online classes due to the COVID-19 pandemic in comparison with previous semesters.".

Question Q3 "Comparing to the traditional methods, what is your perception regarding your comprehension of the subject discussed in this active methodology?" is connected to PBL's objective of enhancing student learning through knowledge contextualization. Figure 8 shows the results of the frequency analysis in this question.

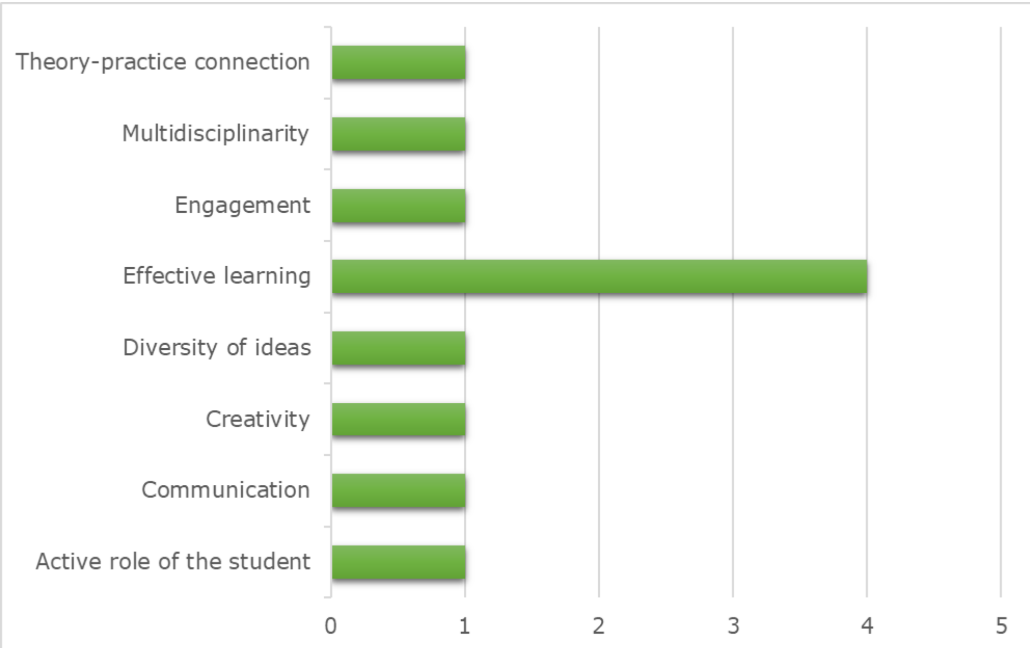

Figure 8 – Local frequency of the concepts identified in the answers to question Q3 "Comparing to the traditional methods, what is your perception regarding your comprehension of the subject discussed in this active methodology?".

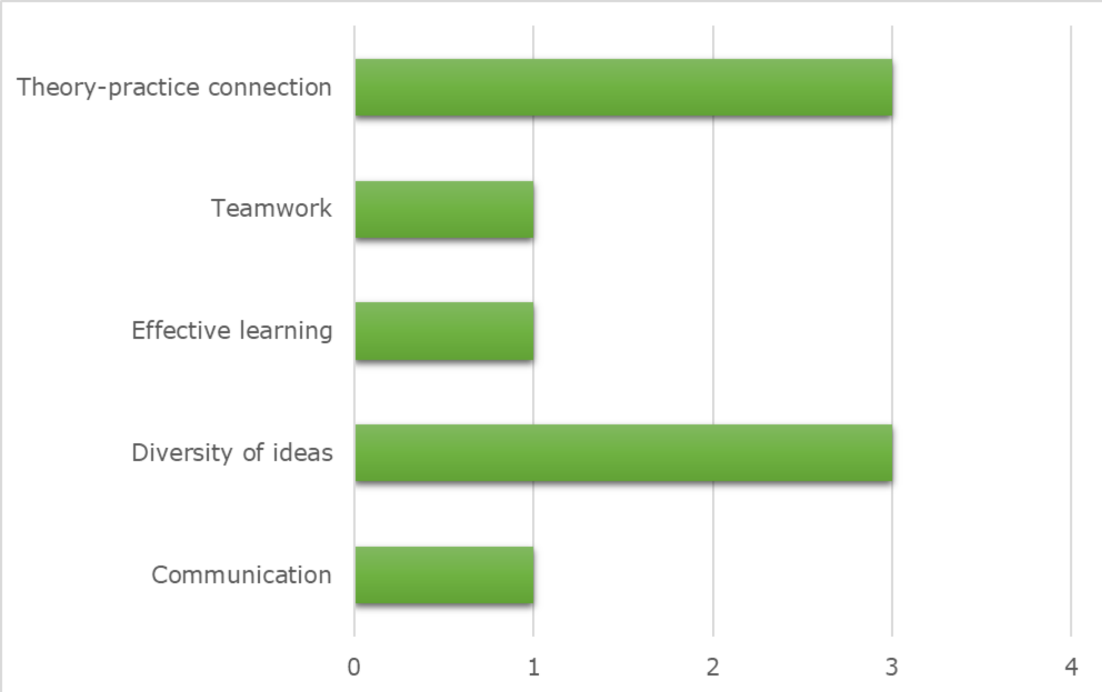

Figure 9 - Local frequency of the concepts identified in the answers to question Q5 "Did you like this experience? Why?".

The students revealed that the most significant reasons that lead them to a positive impression of PBL are the connection between theory and practice and the diversity of ideas, corresponding to 67% of the citations, as shown in Figure 9. This indicates that the aforementioned aspects should be focused upon the implementation of Problem-Based Learning, so to favor even more the engagement and, also, to further aid in softening the impact of the insecurity that might arise from o novel methodology. The connection with the practical environment was also evidenced by Tortorella and Cauchick-Miguel (2017) in their studies, whose Problem-Based Learning model revealed the utilization of methodologies that allow and foster this contact positive to the insertion of the students in the workforce, as it helps enhance the desirable competences.

Synthesis and selection of results, inferences, and interpretations

An interesting finding is that the students manifested perceiving other benefits beyond those found in literature. One of these benefits é the diversity of ideas, which is present in a methodology that encourages debate among the group, and how this factor contributes to the understanding of the subject being taught and to the development of the solution for the proposed problem. This can be seen, for example, in this excerpt: "This kind of methodology made everyone in the group question one another, clarifying doubts and observing diverse points of view, so we achieved better retention of the subject" (S8).

The previous excerpt, collected from student S8's response, indicates a connection between the discussion of different points of view and the effectiveness of the learning process. Within the context of an industrial problem, this clash allows the student to manifest and improve competences of communication and teamwork, so that these differences can be debated and the obstacle overcame in the process of devising a solution, as explains Campos (2020). Furthermore, visualizing a situation from a different approach than the most natural one for each person enriches the learning process, fostering the open-mindedness, another relevant soft skill mentioned by Campos (2019). Student S7 also mentions this aspect in their answer, saying that "[It] is of extreme importance to have multiple opinions regarding only one topic […]", and student S8 reinforces the importance of this aspect to their learning in the following patch: "The more different ideas and points of view, the easier it is to understand."

Effective learning itself was another benefit vastly cited by the students. A patch of student S2's response shows this concept clearly, as follows:

> […] we had a good feeling because we could really understand the subject e how it works and I was able to comprehend more of the subject thinking that I didn't only memorize and that in one week I'll forget. This way it is easier to comprehend what is being done and then do it in practice if necessary (S2).

This excerpt also evidences a connection perceived by the student between knowledge contextualization, connecting with industry practice, and effective learning, reaffirming Problem-Based Learning's role in improving students' readiness for the work environment. Another view of this effectiveness was presented by student S1, on the following patch of their response: "The PBL methodology provides learning based on multidisciplinary, as it allowed the consolidation of knowledge obtained in this and in other courses in the program", notably, the improvement of the multidisciplinary competence, by allowing that subjects from various courses were aggregated to elaborate the solution, just as it is required of the engineer in the workplace.

It is important to notice that the improvement in engagement also allows a more profitable learning, because, as well observed by student S1 in the following patch, the active role of the student contributes to that: "[…] the methodology allows the student to immerse in the learning process, increasing their engagement, because it incites curiosity and the need to debate the best way to solve a given problem."

Another benefit observed by the students was the improvement on the social aspect of the university, severely impacted by the sanitary measures of social distancing. Soares and Del Prette (2015) state that social interaction is important to engagement, and also to maintain the student enrolled in the university. The next excerpt, form student S3's response, shows that: "[..] it is good to get back in contact with the group, even online. The communication and knowledge sharing are good and make us feel less alone, as with only tests and theoretical classes the students end up not having much contact." Form that it is possible to infer that the interpersonal contact promoted by the constant teamwork of Problem-Based Learning enables, at least partially, the satisfaction of this social need, working in favor of the reduction of evasion rates.

Conclusions

Regarding the objectives of this research, it is possible to state that the first objective, implementing Problem-Based Learning on the Production Engineering graduation program, was achieved, and the proposed structure with a class assigned to present the methodology, and a second class to present a common basis of concepts, proved effective. However, the evaluation time frame of 1 month was inconclusive, suggesting the need for future research on this topic.

The second objective, the fostering of soft skills, was achieved, as shown by the Content Analysis, evidencing the soft skills manifested by the students, and promoting knowledge contextualization, which promotes better comprehension of the subject.

The third objective, increasing student engagement, was also achieved, as was concluded that applying Problem-Based Learning promoted an increase in student motivation, thus increasing engagement and enhancing the profitability of learning in online classes.

During the development of the research, some questions emerged, which are highlighted here as future research suggestions: perform a similar study with a larger population and sample and investigate the relationship between the concepts cited in the answers to questions Q2 and Q3 that were not directly connected to the goal asked about in each question. Also, it should be noted that the conclusions made in this research, given the sample size, show that PBL was effective on a specific group of students. Further research is needed to determine if these results can be replicated in different groups, with different characteristics.

Some difficulties and watchpoints were also observed, especially referring to the definition of the problem. It is natural that the data provided by industry does not always fully contemplate the analysis of the situation, be it because of trade secrets, or because the data is not collected, and that should be observed by the professor when proposing the problem. The authors understand that the ideal is to bring a representative of the company to present the problem to the students, so that they can clear their doubts regarding the context and their understanding of the situation, enabling a richer work for the students. However, attention is necessary to avoid creating a "cemented" problem, as not to direct the students to a specific solution. Finding that balance is not an easy task, and so the planning of the methodology and the classes should be conducted with attention.

Finally, it was concluded that, for the group of students that was analyzed, the Problem-Based Learning methodology was capable of satisfying the need observed of workplace readiness, promoting competence fostering, knowledge contextualization and the paradigm shift so the students become the active subjects in their learning process, enabling them to learn how to study and think by themselves.

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