IMPLEMENTING PROBLEM-BASED LEARNING IN THE TEACHING AND LEARNING PROCESS OF LINEAL ALGEBRA WITHIN METALLURGICAL AND MATERIALS ENGINEERING PROGRAM

EL APRENDIZAJE BASADO EN PROBLEMAS EN EL PROCESO DE ENSEÑANZA APRENDIZAJE DEL ÁLGEBRA LINEAL EN LA CARRERA INGENIERÍA EN METALURGIA Y MATERIALES

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ABSTRACT

This work is a proposal of didactic strategy to implement Problem-Based Learning (PBL) in the Metallurgic and Materials Engineering career at the University of Moa to improve the teaching- learning process due to the academic performance in the subject of Mathematics Topics. The research employed a quantative, descriptive, and exploratory approach, as well as empirical and mathematical-statistical methods such as reviews, direct observation and documentary analysis in order to explore the impact of the proposal. The results showed that the implemented strategy has a significant impact in motivation and consequently in the students' learning; besides contributing to the metallurgic engineers' formation trained for solving industrial problems with a scientific rigor.

KEYWORDS: logical thinking; motivation; academic performance; topics of Mathematics

RESUMEN

Se propuso una estrategia didáctica para aplicar el Aprendizaje Basado en Problemas (ABP) en la carrera Ingeniería en Metalurgia y Materiales en la Universidad de Moa para mejorar el proceso de enseñanza aprendizaje debido al bajo rendimiento académico en la asignatura Temas de Matemática. Se utilizó un enfoque cuantitativo, de carácter descriptivo y exploratorio, así como métodos empíricos y matemáticos-estadísticos como el análisis documental, la observación y las encuestas para explorar el impacto de la propuesta. Los resultados muestran que, la aplicación de la estrategia trazada genera un impacto significativo en la motivación y, por consiguiente, en el aprendizaje de los estudiantes; además, contribuye a formar ingenieros metalúrgicos capacitados para resolver problemas industriales con rigor científico.

PALABRAS CLAVE: pensamiento lógico; motivación; rendimiento académico; Temas de Matemática

INTRODUCTION

Mathematics is an abstract science concerned with the study of quantities, structures, patterns, and changes. It is based on logical reasoning and uses symbolic language to formulate theories and solve problems. Through its various branches, such as Arithmetic, Algebra, Geometry, and Calculus, it provides the necessary tools to understand and describe phenomena in the real world. Its rigorous and precise nature makes it a fundamental pillar in many scientific and technical disciplines.

A branch of Algebra (AL) that deals with the study of systems of linear equations and linear transformations has become an essential tool in modern engineering due to its capacity to model, analyze, and solve complex problems across a wide variety of fields (Castro, Sánchez, Toscano & Pamela, 2023).

Furthermore, it has enabled significant advances in the design, analysis, and simulation of systems and processes in an extensive range of disciplines. In summary, linear algebra has gained great importance for engineering and must therefore be considered in curricula.

The teaching-learning process of Linear Algebra in Engineering majors contributes to the development of logical and algorithmic thinking and provides the fundamental foundations for a specialist in these sciences, given that every engineer considers technical and scientific representations in mathematical terms, which reflect the quantitative and qualitative features of the phenomena they study (León et al., 2019).

Santana, Esquivel, Avena & Ortíz (2015); Hurtado & Pupo (2016); Cavani (2020); and Osorio et al. (2023) emphasize that Linear Algebra is part of the curriculum in engineering and other sciences, hence the relevance of understanding its main concepts and teaching it in light of its applications. Likewise, Loaiza (2023) reports that when working with the ELI Methodology (Improvisation-Free Teaching), Problem-Based Learning, case studies, and innovative tools, such as Socrative, GeoGebra, Kahoot, and Simbolab, students improved their comprehension of the content and also related the applicability of Linear Algebra topics to problems in their professional field.

In the area of didactics, many researchers have pointed out the role of teaching-learning methods, especially active ones, in achieving developmental learning in students, as referenced by Tunis et al. (2020).

González (2012) states that active teaching-learning methods are those in which the student participates actively and the teacher becomes a guide, a facilitator, and a motivator rather than a transmitter of knowledge; examples include problem-based methods grounded in problem-oriented teaching, with Problem-Based Learning (PBL) standing out among them.

PBL focuses on solving problems related to students' interaction with their professional environment. The essence of the method consists of identifying, describing, analyzing, and solving such problems, which is achieved with the teacher's assistance.

Faced with any situation presented to the students, they will be capable of innovating, integrating, and applying knowledge associated with their profile (Velázquez, García, Zúñiga & Landin, 2021).

Moreover, the use of the Problem-Based Learning method is one of the most innovative approaches in current academic training (Garcet, 2021; Manso & Garrido, 2022; Cámac et al., 2023; Escalera et al., 2023).

In the case of the University of Moa Dr. Antonio Núñez Jiménez, a higher education institution offering various majors, including Metallurgical and Materials Engineering, the need for this research becomes evident when considering the current challenges faced in teaching branches of mathematics such as Linear Algebra.

Lack of motivation, limited recognition of Linear Algebra applications in Metallurgical Engineering, and low academic performance are recurrent problems that affect not only students' academic success but also their perception and attitude toward science.

The general objective of this research is to develop a didactic strategy for the application of the PBL teaching-learning method in the process of teaching Linear Algebra in the Metallurgical and Materials Engineering major at the University of Moa Dr. Antonio Núñez Jiménez. This objective is based on the premise that Problem-Based Learning can serve as a powerful tool to transform Linear Algebra instruction, making abstract concepts more accessible and understandable to students through real-world problems linked to their field.

MATERIALS AND METHODS

The methodological approach of this research is according to a mixed research methodology because it combines qualitative and quantitative methods, techniques, and procedures, with a descriptive and exploratory nature. Empirical methods, such as documentary analysis, observation, surveys of students and teachers, and mathematical-statistical methods were used with two groups from the program to explore the methods employed in teaching Linear Algebra.

Population and sample

The population consisted of 67 students from the full-time course in the Metallurgical and Materials Engineering major. The sample, selected through non-probabilistic convenience sampling, included 34 students from the first and second years of the referred major. The choice of this sample was based on the availability and interest of students and professors to participate in the study. Additionally, five professors from the Mathematics Department participated, allowing for cross-referencing and complementing the results obtained from the students, providing a comprehensive view of the intervention's impact.

Instruments

To better understand the level of knowledge and use of teaching-learning methods by professors, a survey was applied to five Mathematics professors. They were selected to share their experiences and perspectives on how the use of this method in the teaching-learning process of Linear Algebra content within the Mathematics Topics for Metallurgy course has influenced their students' motivation. The Likert-type questionnaire consisted of 21 items on a rating scale ranging from 1 (indicating «Strongly disagree») to 5 (indicating «Strongly agree»).

Similarly, the instrument used to evaluate the quality of instruction received by students consisted of 28 items organized into four dimensions or subscales: importance of linear algebra, learning of linear algebra, classroom development with the professor, and professional training in linear algebra within the program. Participants rated each item on a scale from one to five.

RESULTS

Observation

During classroom observations, the following aspects were verified: the definition, explication, and orientation of objectives; the teaching-learning methods employed; content treatment; resources used; forms of class organization; evaluation; guidance of independent study; and communication

with students. It was observed that the professors, each with their own style, fulfilled each of the evaluated teaching categories.

Survey to professors

A survey was conducted with five Mathematics *professors* members to assess their knowledge and perception of Problem-Based Learning in the classroom, as shown in Figure 1.

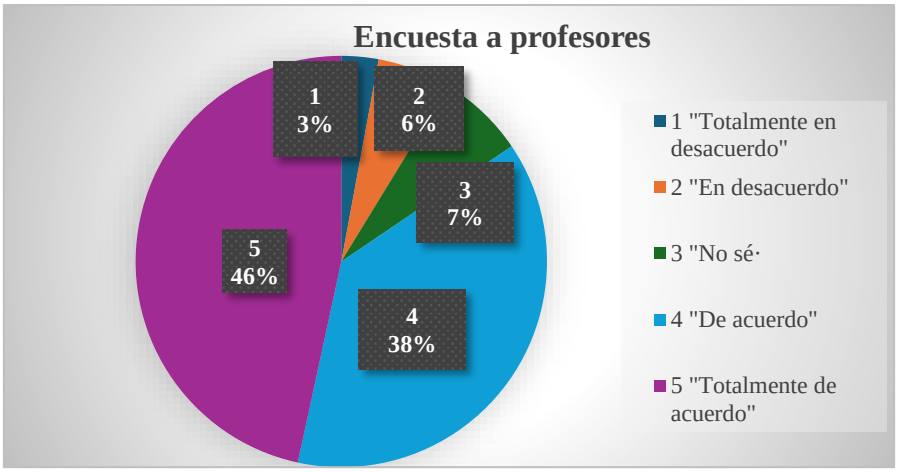

Figure 1. Professors' perception of the application of the PBL method

It was corroborated that 84% of the professors support that Linear Algebra content is fundamental for the training of metallurgical engineers, promotes active participation, collaborative work, and debate among students to solve Linear Algebra problems linked to their major, and that the teaching methods employed adapt to the different needs and learning styles of students. Furthermore, they incorporate digital tools (MATLAB, Python, simulators) to reinforce learning and use active methods (PBL, case studies, projects) to teach abstract Linear Algebra concepts, providing timely and constructive feedback on student performance.

Despite this, it should be noted that, of the five professors surveyed, only one holds a degree in Mathematics, two are Associate professors, two have 15 years of experience or more, and only three hold a Master's degree, which could be considered a weakness in the teaching-learning process of the subject.

Survey to students

A survey was conducted with 34 students to improve the quality of instruction received in the Mathematics Topics course (Figure 2).

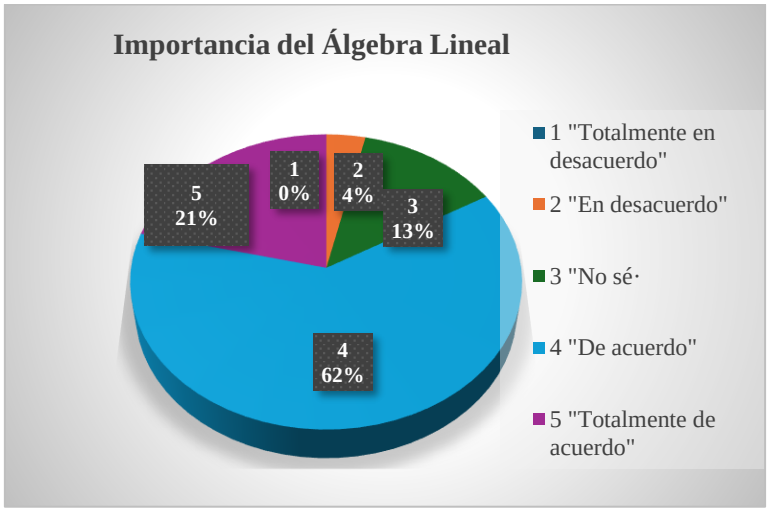

Figure 2. Perception of the importance of Linear Algebra (AL)

It was found that 62% of students consider Linear Algebra necessary for the major, for their academic progress, and applicable to other studies, while also helping them think, reason, and develop abstract thinking.

Also, as shown in Figure 3, 49% of students feel satisfied with their learning of Linear Algebra because they have learned to calculate correctly, apply algorithms, make conjectures, and analyze problem situations.

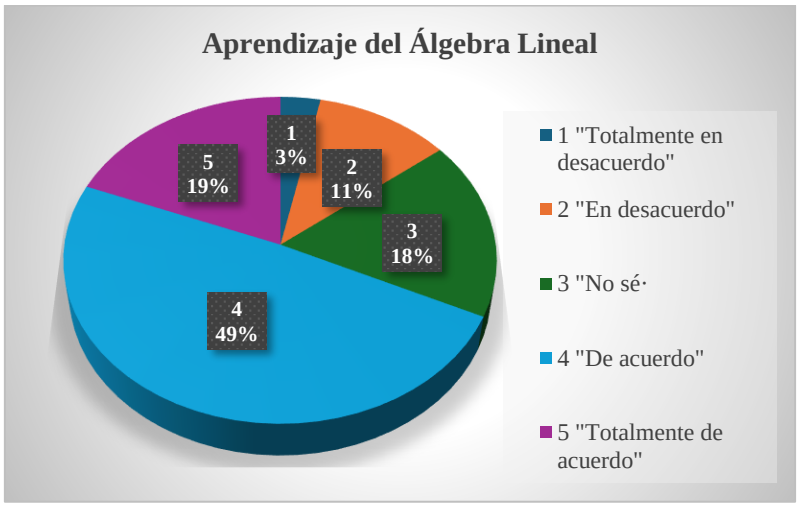

Figure 3. Perception of Linear Algebra learning

Furthermore (Figure 4), 86% of students agree that the profesor uses dialogue to guide them in understanding new content, demonstrates adequate mastery and the ability to explain it clearly, and systematically works on aspects to be considered for solving problems related to the profession, as well as ways to solve them.

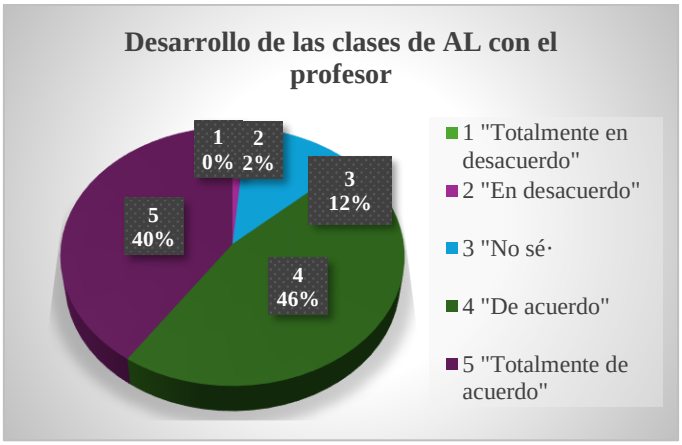

Figure 4. Classroom development with the professor

Figure 5 shows that 53% of students agree that learning Linear Algebra is essential for developing competencies in Metallurgical and Materials Engineering major, that the concepts learned are applicable to real problems in this field, and that it provides a solid foundation for understanding other advanced courses in the referred major, as it allows them to develop analytical and problem-solving skills that are useful and applicable in their projects and professional practices.

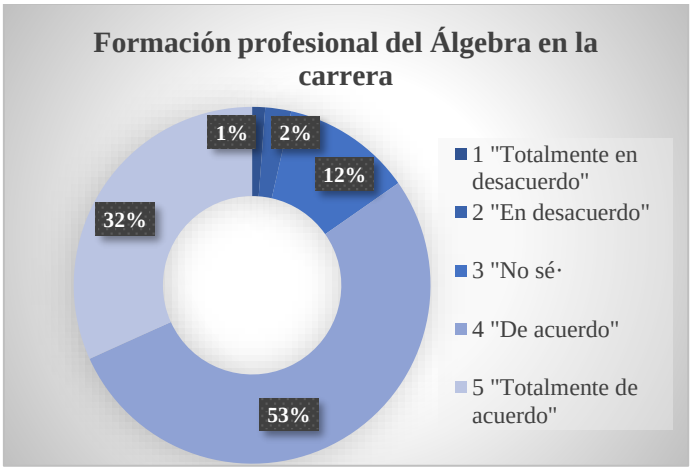

Figure 5. Professional training in Linear Algebra within the program

Academic Performance

Documentary review of course records and partial tests related to the Algebra topic (Figures 6-7) yielded the following results:

1. 56% of students achieved a grade of 4 points in 2021, this being the highest score that year, while 20% obtained a score of 2 points. In 2022, only 4% obtained a grade of 4 points, the highest score, while 96% obtained a grade of 3 points on the partial test. In 2023, 35% achieved a grade of 5 points; however, 47% received a score of 2 points on said test.
2. In 2021, 7 students finished the course with 5 points, while 2 failed and 5 obtained a final grade of 3. In 2022, 8 students achieved a final grade of 5; despite this, 3 failed the course and 9 finished with 3 points. In 2023, only 3 students did not pass, 11 finished with a final grade of 3 points, and only 3 achieved the maximum grade of 5 points.
3. The average final grade over the three years ranged from 3.95, 3.74, and 3.46, respectively, decreasing as the courses progressed, while the average partial test grade during that period varied: 3.36 in 2021, 3.04 in 2022, and 3.41 in 2023, indicating that it decreased from 2021 to 2022 and increased from 2022 to 2023. In both cases, it should be noted that the average partial and final grades never reached 4 points, an unfavorable outcome to consider in the development of the teaching-learning process of the course within the major.

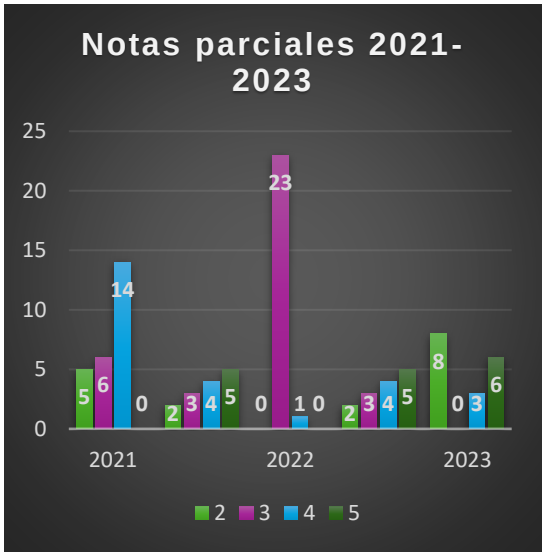

Figure 6. Partial grades 2021-2023

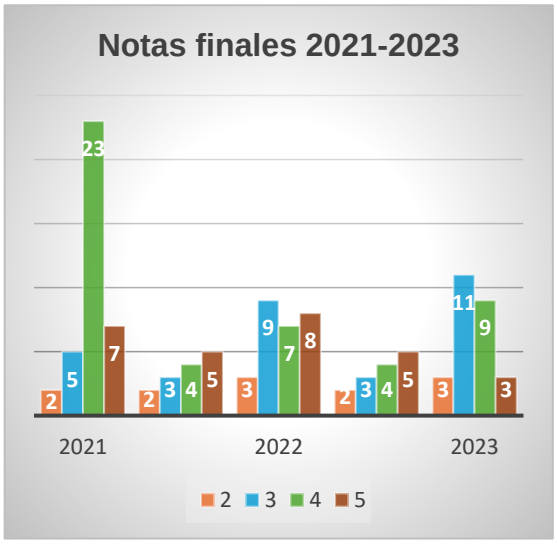

Figure 7. Final grades 2021-2023

DISCUSSION

Although the majority of students (62%) recognize the importance of Linear Algebra for their program and development, 17% do not consider it relevant to their professional profile. Furthermore, 32% are not fully satisfied with what they have learned, indicating a possible disconnect between the teaching of the subject and its practical applications in the field of Metallurgical and Materials Engineering.

Some 14% of students express disagreement with the teaching methods used by professors, signaling a need to review and diversify pedagogical strategies to cater to all students.

The analysis of the records and partial tests reveals a central problem:

- ✓ The average grades (both partial and final) never reached a value of 4 points in the three years analyzed.
- ✓ The average final grade showed a declining trend: 3.95 (2021), 3.74 (2022), 3.46 (2023).
- ✓ There is a high percentage of students with low or failing grades. For example, in 2023, 47% obtained a grade of 2 on a partial test, and only 3 students from a group passed with the highest grade (5 points).

The staff has a significant weakness:

- ✓ Only one of the five professors holds a degree in Mathematics.
- ✓ Only three hold a Master's degree in Higher Education.
- ✓ Although two professors have more than 15 years of experience, this does not translate into satisfactory academic results, suggesting that experience alone does not guarantee effectiveness.

It should be noted that they are not graduates in Mathematics; nor have they taken didactics courses or have pedagogical training. Therefore, how do they know about active methods, or what PBL is? Their actions are not aligned with the foundations of didactics and pedagogy; thus, they lack the main

foundations to effectively develop the teaching-learning process, and consequently, they are unable to anticipate students' difficulties and design specific strategies to guide their discovery.

The main deficiencies lie in a combination of low and declining academic results, a divided perception among students regarding the usefulness of the subject, teaching methods that fail to connect with a portion of the students, and a staff whose foundational academic training in didactics may limit the depth and effectiveness of instruction.

Based on the deficiencies detected in the study, the authors consider that PBL is the solution to the identified weaknesses because it transforms Linear Algebra from an abstract subject into a practical tool for Metallurgical and Materials Engineering major. Its active and contextualized approach:

- ✓ Improves learning by making it meaningful.
- ✓ Connects Linear Algebra with the professional profile.
- ✓ Reinforces utility and consolidates knowledge by applying what is learned in other subjects and in practice.
- ✓ Not only improves the teaching of algebra but also contributes to the training of metallurgical engineers capable of solving industrial problems with scientific rigor.

Parra (2003) states that the Problem-Based Learning method has the following advantages:

1. Develops critical thinking in students.
2. Strengthens the values of tolerance, respect, and responsibility.
3. Improves the level of argumentation and information management.
4. Enables the acquisition of skills and competencies for solving mathematical problems.

Alarcón, Gastelú & Domínguez (2023) conducted a systematic literature review related to PBL and determined that it promotes the development of transversal, digital, communicative, and collaborative competencies, impacting the formation of mathematical competence as a higher form of understanding the abstract mathematical structure of objective reality phenomena.

The didactic strategy based on PBL proposed here will transform the Linear Algebra experience from an arid, abstract subject into a living, relevant, and engaging discipline. Students not only learn mathematical concepts but also develop critical thinking, collaboration, and problem-solving skills that are absolutely essential in the modern professional world. It is undoubtedly one of the most effective ways to «humanize» and connect advanced mathematics with the needs and interests of students.

The term «strategy» refers to a planning system applicable to a coordinated set of actions to achieve a goal. The strategy must be based on a method, but unlike the latter, the strategy is flexible and can take shape based on the goals to be achieved. In its application, the strategy may use a series of techniques to achieve its objectives.

According to Sepúlveda & Véliz (2013), the didactic strategy is conceived as the structure of activity in which objectives and contents become real. Parra (2003) maintains that teaching-learning strategies constitute sequenced, ordered, and planned activities, as well as flexible and adaptive procedures that the professor chooses to enable the understanding of certain topics, allowing learning to be more effective.

Torres, Suárez & Ocampo (2017); Lima (2012) consider the didactic strategy as a set of sequential and interrelated actions that, starting from an initial diagnosis and the proposed objectives, guide the development of the teaching-learning process.

The authors agree that a didactic strategy is an organized and sequential set of actions and techniques that, based on an initial diagnosis, the professor plans and uses to activate learning, guiding the process toward proposed objectives and adapting to the needs of the teaching-learning process of Linear Algebra.

The implementation process of the didactic strategy in the Mathematics Topics for Metallurgical and Materials Engineering major was structured in four stages, detailed below:

I. DIAGNOSIS: applied to characterize the current state of students' learning of Linear Algebra and its link to the professional profile.

Actions:

a) Adapt the indicators for diagnosis according to the specific moment and conditions of the student group.

b) Selection and/or development of instruments.

c) Application of the selected instruments to the involved parties.

d) Interpretation of the main results obtained.

II. PLANNING: the set of actions is planned based on the results obtained from the instruments applied during the diagnosis stage, as well as the organizational forms to be used in the strategy and evaluation.

Actions:

a) Determine the professional problems to be addressed.

b) Determine the teaching-learning forms to be used.

c) Availability of technological resources necessary to carry out the actions that enable change.

d) Define the evaluation methods.

III. EXECUTION: in this stage, the actions planned are executed, considering the demands of educational practice.

Actions:

a) Problem presentation, problem definition, group work, formulation of learning objectives, research, task division, individual work, feedback within working groups, synthesis and representation, evaluation and self-evaluation, knowledge generation, and skill development.

IV. EVALUATION: aimed at evaluating the application of the Problem-Based Learning method in the teaching-learning process of Linear Algebra.

Actions:

a) The professor evaluates using the established method, which should not consist solely of the traditional evaluation procedure but rather an alternative that allows for comprehensive assessment at different moments of the student's progress.

b) In this regard, evaluation and self-evaluation of each activity participant should be fostered through criteria that develop self-criticism and corresponding reflection on identified deficiencies, or congratulation and academic reinforcement of acquired achievements or skills developed by team members.

In summary, the results of this research coherently reflect the relationship between didactic categories while providing a set of flexibly implementable activities and procedures. Solving contextualized problems enables greater student motivation by demonstrating the immediate utility of Linear Algebra in the professional profile; furthermore, it contributes to training metallurgical engineers capable of solving industrial problems with scientific rigor.

CONCLUSIONS

The application of the didactic strategy based on Problem-Based Learning transforms the learning experience, making it more dynamic, participatory, and meaningful for students. By linking PBL to real problems of the metallurgical profile, a direct positive impact is generated on academic performance by making abstract Linear Algebra concepts more accessible, thereby contributing to improved student motivation.

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