REVISTA INVECOM
ISSN en línea: 2739-0063

Meaningful learning of Physics with MatLab

Aprendizaje significativo de la Física con MatLab

Received: 30/05/2025 - **Accepted:** 28/08/2025

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Abstract

The purpose of this study was to evaluate the effectiveness of Matlab software as a teaching tool for promoting meaningful learning in physics among students at the Faculty of Engineering of the National Agrarian University of La Selva. To this end, a sample of 100 students was surveyed using a 30-item questionnaire administered at two different times: a pretest, before the software was implemented, and a posttest, after it was used in the teaching-learning process. An ordinal and interval rating scale was used, which allowed for more accurate measurement of the progress made by the participants. Under a quasi-experimental design, the results showed significant progress: 90% of the students achieved the expected level of achievement, 8% were in the process of achieving it, and 2% achieved an outstanding level. Statistical analysis confirmed that the use of Matlab has a positive impact on the development of meaningful learning in the university setting.

Keywords: physics, meaningful learning, Matlab software.

Resumen

El presente estudio tuvo como finalidad evaluar la efectividad del software Matlab como herramienta didáctica para promover el aprendizaje significativo en la asignatura de Física en estudiantes de la Facultad de Ingeniería de la Universidad Nacional Agraria de la Selva. Para ello, se trabajó con una muestra conformada por 100 estudiantes, a quienes se les aplicó un cuestionario de 30 ítems en dos momentos: un pretest, antes de la implementación del software, y un postest, luego de su aplicación en el proceso de enseñanza-aprendizaje. La escala de valoración utilizada fue de tipo ordinal e intervalar, lo cual permitió medir con mayor precisión el progreso alcanzado por los participantes. Bajo un diseño cuasiexperimental, los resultados mostraron avances significativos: el 90 % de los estudiantes alcanzó el nivel de logro esperado, el 8 % se ubicó en proceso y el 2 % logró un nivel destacado. El análisis estadístico corroboró que el uso de Matlab incide positivamente en el desarrollo del aprendizaje significativo en el ámbito universitario.

Palabras clave: física, aprendizaje significativo, software Matlab.

Introduction

In the university academic realm, the teaching of Physics has been characterized by maintaining a traditional structure that hinders the incorporation of innovative methodological approaches. This resistance has resulted in a disconnection between the way the subject is taught and the current learning needs of students. One of the main challenges students face is the high level of abstraction inherent in this discipline and its close relationship with mathematical language (Duit et al., 2014).

Various studies have shown that the teaching of Physics at most universities relies on transmissive methodologies, focused on the mechanical resolution of quantitative problems extracted from textbooks. While this approach may be useful in specific contexts, it does not guarantee a deep understanding of concepts nor does it foster a meaningful interpretation of results. In this model, mathematical skill prevails over the development of procedural and cognitive abilities necessary for analyzing physical phenomena (Guisasola et al., 2006; Perales, 2006).

This traditional approach proves insufficient in the face of contemporary demands, both social and professional, that require students capable of actively participating in the construction of knowledge, solving complex problems, and developing conceptual, practical, and communicative competencies. In the field of science education, the importance of situating educational processes in an appropriate context has been emphasized, promoting methodologies that encourage autonomous research, critical thinking, and a logical understanding of scientific knowledge (Solbes et al., 2007). Furthermore, in the professional sphere, engineers are expected to

possess not only a solid theoretical foundation but also the skills to handle technological tools and apply acquired knowledge in practice (Schmal, 2015; Soares et al., 2013).

In this context, addressing problematic situations is an essential element for the academic and personal development of students. Mastering this skill involves not just applying formulas or following predetermined steps; it also requires the development of cognitive skills related to interpretation, modeling, and argumentation. The complexity of this process has led to educational proposals aimed not only at improving content but also at transforming the way these fundamental competencies are taught.

The main objective of this study is to investigate whether the integration of Matlab software as an educational tool contributes to enhancing meaningful learning in the Physics course for engineering students at a public university in Peru. Additionally, it aims to analyze and compare the level of learning in the conceptual, procedural, and communicative areas between an experimental group that used Matlab and a control group that followed the conventional educational method.

The adopted approach responds to the professional training needs of engineers, who must have the ability to understand complex concepts and process information to solve practical problems in environments such as laboratories. The educational strategy consisted of organizing learning sessions focused on the joint analysis of problematic situations, followed by conducting experiments using Matlab software and physical measurement and data acquisition devices.

During each session, students worked in teams under the guidance of an instructor or technical assistant, developing activities that combined practical experimentation with the use of specialized programs. Subsequently, they prepared reports summarizing results, analyzing data, and responding to specific questions. This methodology aimed to promote active and meaningful learning for all participants.

The results of the study reveal statistically significant differences between the experimental group and the control group, particularly in theoretical argumentation, the practical application of learned concepts, and the ability to communicate on the subject matter. Difficulties identified among some students, related to organizing ideas or applying differential and integral calculus in physical contexts, were addressed through collaborative activities and ongoing instructor support. Quantitatively, a considerable increase in mean scores for all three dimensions of meaningful learning was observed: from 62.1 in the general pretest to 104.4 in the posttest; in the conceptual dimension, from 21 to 35.4; in the procedural dimension, from 22.2 to 37.2; and in the communicative dimension, from 18.9 to 31.8.

Methodology

The research was conducted using a quasi-experimental design, suitable for contexts where random assignment of participants is not possible. The study was applied to engineering students at the National Agrarian University of La Selva enrolled in the Physics course. Two groups were formed: an experimental group (EG), which used Matlab software during the learning sessions, and a control group (CG), which followed the traditional teaching approach. Both groups were assessed using a pretest and a posttest to compare the levels of meaningful learning achieved.

In the experimental group, teamwork was promoted to analyze experimental situations relevant to the subject and resolve them using Matlab as a support tool. Each session included the presence of an instructor or specialized assistant who guided the activities according to a pre-designed roadmap. At the end of each practical session, students wrote a report detailing the data obtained, interpreting results, and answering the initially posed questions.

The program was implemented over 10 weekly sessions, each lasting two hours. Prior to the start, a diagnostic assessment was administered, and a posttest was conducted at the end to measure the impact of the intervention. The topics covered included fundamental principles of Physics such as density, pressure, fluids, calorimetry, ideal gases, and electrical circuits, as well as specific aspects of Matlab, including arithmetic operations, matrices, functions, two-dimensional and three-dimensional graphs, and interpolation.

Table 1. *Schedule of learning sessions*

No.	Physical Content	Matlab Application
1	Pre-test	—
2	Calculation of the density of a homogeneous substance	Arithmetic calculations
3	Analysis of the density of an immiscible liquid	Scalar variables
4	Archimedes' Principle	Vectors
5	Velocity of a fluid	Matrices

6	Emptying time in a system	Functions
7	Specific heat of aluminum	Two-dimensional graphs I
8	Isochoric process in an ideal gas	Two-dimensional graphs II
9	Isothermal process in an ideal gas	Three-dimensional graphs
10	Analysis of a circuit in loops / Electric transformer	Polynomials / Miscellaneous functions
11	Post-test	—

A pilot study was conducted with 30 volunteer students, aimed at identifying issues in the wording of the items, evaluating the understanding of concepts, and verifying the clarity of the proposed situations. The results indicated that participants understood the statements, although they expressed difficulties in mathematical modeling, which justified the relevance of integrating Matlab into the instructional process. Based on this initial validation, the instruments were adjusted, and formal data collection proceeded.

The dependent variable, meaningful learning, was evaluated based on the average of the pretest, practical session grades, and posttest scores. To ensure the quality of the instrument, various validity and reliability tests were applied:

- **Content validity**: Determined using Aiken's V coefficient, yielding a value of 0.999, indicating a high relevance of the items.
- **Criterion validity** (indirect concurrent): Obtained by comparing the questionnaire results with a midterm exam, achieving a value of 0.775.
- **Construct validity**: Evaluated through factor analysis, with a KMO index of 0.732 and Bartlett's test = 0.000, confirming the appropriateness of the model.

Regarding reliability, Cronbach's alpha coefficient was employed, resulting in a value of 0.948, demonstrating very high internal consistency of the instrument. The sample comprised 100 students distributed non-randomly across the two groups (experimental and control).

Table 2. *Characteristics of participating groups.*

Group	Assignment	Treatment
Experimental Group	Agricultural Engineering (n = 50)	Use of Matlab software to promote meaningful learning in Physics
Control Group	Other engineering specialties (n = 50)	Traditional teaching based on lectures and problem-solving exercises

All participants signed an informed consent form, ensuring their voluntary participation and the ethical and confidential handling of the collected information.

Instruments and evaluation indicators

For the evaluation of meaningful learning, the following resources were employed:

1. Practical sessions using Matlab.
2. Written tests (pretest and posttest).
3. Technical laboratory reports.
4. Analytical performance rubrics.

The questionnaire was structured with a 5-level Likert scale, distributed across three dimensions:

- Items 1 to 10: Conceptual content.
- Items 11 to 21: Procedural content.
- Items 22 to 30: Communication.

Table 3. *Evaluation rubric.*

Dimension	Definition	Scale (1–5)
Conceptual Content	Understanding of physical principles and structuring of conceptual systems explaining concrete phenomena.	Very low (1) to Very high (5)
Procedural Content	Application of strategies, techniques, and representations in solving physical problems.	Very low (1) to Very high (5)
Communication	Ability to transfer knowledge to new situations and explain phenomena based on general principles.	Very low (1) to Very high (5)

Finally, the results analysis was conducted using SPSS v20, applying descriptive statistics and the Student's t-test for independent and related samples to compare mean differences within and between groups.

Results

The results obtained allow for a clear evaluation of the impact of implementing Matlab software on the meaningful learning of Engineering students in the Physics course at the National Agrarian University of La Selva. To achieve this, the achievement levels reached in each dimension of the study variable—conceptual, procedural, and communicative—were analyzed, comparing the differences between the pretest and posttest of the experimental and control groups.

Global results of meaningful learning levels

At the general level of meaningful learning, prior to the application of the proposal with Matlab, the experimental group had 26% of students at the initial level and 74% in progress, with no records at higher levels. After the intervention, the posttest results showed a notable change: 90% of students reached the prior achievement level, 8% were in progress, and 2% achieved the distinguished level, completely eliminating the initial level.

In contrast, the control group showed no significant improvements. In the pretest, 38% of students were at the initial level and 62% in progress. Following traditional classes, the posttest reflected that 16% remained at the initial level and 84% in progress, with no students reaching prior or distinguished achievement levels.

Table 4. *Level of meaningful learning in control and experimental groups*

Level	Experimental Group	Control Group
	Pre-test	Post-test
Distinguished	0 (0%)	1 (2%)
Prior Achievement	0 (0%)	45 (90%)
In Progress	37 (74%)	4 (8%)
Initial	13 (26%)	0 (0%)
Total	50	50

These results reflect the effectiveness of the instructional proposal based on Matlab, demonstrating a significant improvement in the understanding and application of Physics content.

Results by dimension of meaningful learning

- **Conceptual dimension:**

Before using Matlab software, 30% of the experimental group was at the initial level and 70% in progress. Following the intervention, 80% reached the prior achievement level, 14% achieved the distinguished level, and only 6% remained in progress, with no records at the initial level. In contrast, the control group exhibited no significant changes: in the posttest, 84% remained in progress and 16% at the initial level, with no students reaching higher levels.

- **Procedural dimension:**

In the experimental group, before the intervention, 42% (21 students) were at the initial level and 58% (29 students) in progress. After implementing Matlab, 84% reached the prior achievement level, 2% the distinguished level, and 14% remained in progress, with no students at the initial level. In the control group, prior to the intervention, 36% were at the initial level, 62% in progress, and only one student reached the prior achievement

level. After traditional teaching, 26% continued at the initial level and 74% in progress, with no substantial improvements.

- **Communicative dimension:**

Prior to the intervention, 24% of the experimental group was at the initial level and 76% in progress. After working with Matlab, 86% reached the prior achievement level, 10% the distinguished level, and only 4% remained in progress, completely eliminating the initial level. Conversely, the control group maintained a similar trend to the initial level: in the pretest, 38% were at the initial level and 62% in progress; in the posttest, the percentages changed minimally, with 4% at the initial level and 96% in progress.

Descriptive statistics of scores by dimensions

The following statistical data obtained in each dimension includes minimum, maximum, average, standard deviation, and coefficient of variation.

Table 5. *Descriptive statistics of scores by dimensions in the Physics course.*

Variable	Group	Test	Minimum	Maximum	Mean	Std. Dev.	C.V. (%)
Conceptual	Experimental	Pre-test	16.0	25.0	21.0	2.3	11.1
		Post-test	27.0	45.0	35.4	3.8	10.7
	Control	Pre-test	15.0	26.0	20.2	2.5	12.2
		Post-test	14.0	28.0	22.8	3.1	13.8
Procedural	Experimental	Pre-test	17.0	27.0	22.2	2.3	10.5
		Post-test	27.0	44.0	37.2	4.1	10.9
	Control	Pre-test	17.0	33.0	22.8	3.1	13.7
		Post-test	14.0	30.0	23.3	3.6	15.3
Communication	Experimental	Pre-test	13.0	26.0	18.9	2.4	12.5
		Post-test	25.0	39.0	31.8	3.1	9.6
	Control	Pre-test	12.0	24.0	18.1	2.5	13.9
		Post-test	15.0	26.0	21.2	2.2	10.2
Total learning	Experimental	Pre-test	54.0	70.0	62.1	3.7	5.9
		Post-test	82.0	127.0	104.4	8.9	8.5
	Control	Pre-test	53.0	70.0	61.2	3.5	5.7
		Post-test	48.0	80.0	67.3	7.4	11.0

With these results, this section concludes by detailing the evolution of students in each evaluated dimension and evidencing the positive impact of using Matlab in the teaching context of university-level Physics.

Discussion

The findings from this research reveal a significant impact of using Matlab software as a teaching tool to enhance meaningful learning in the Physics course for Engineering students at the National Agrarian University of La Selva. When comparing the pretest and posttest results in the experimental group, notable advances were

observed across the three evaluated dimensions—conceptual, procedural, and communicative—while the control group, which adhered to traditional teaching methods, showed minimal or no improvements.

Overall, as evidenced in Table 3, prior to the implementation of the Matlab-based instructional strategy, a considerable percentage of students in the experimental group (74%) were at the progress level, with a smaller group (26%) at the initial level. After the implementation, the lower levels were eliminated, with 90% reaching the prior achievement level and 2% achieving the distinguished level. This positive quantitative evolution suggests that the methodological proposal promoted a deeper and more active learning of Physics content, aligned with Ausubel's (1995, 2002) principles of meaningful learning.

These results align with Carapaz (2014), who argues that the use of technological resources such as Matlab supports the academic development of both teachers and students by creating an innovative learning environment that positively impacts the teaching of Physics and Mathematics. In his study, he highlights that these resources facilitate the dynamic transmission of knowledge and improve the representation and communication of concepts.

Similarly, Marchisio (2014) emphasizes that integrating simulation tools in teaching promotes conceptual and procedural understanding. It is not enough to simply introduce technology into the classroom; educators must be trained to understand its didactic potential and adapt its use to specific contexts. In this regard, the experience with Matlab allowed, through practical exercises, to model physical phenomena and visualize their results in real-time, thereby facilitating students' appropriation of knowledge.

The analysis regarding the conceptual dimension showed significant progress. Before the intervention, most students in the experimental group were at the progress level; after implementing the program with Matlab, 80% advanced to the prior achievement level and 14% to the distinguished level, with no cases at lower levels. This improvement aligns with Yanitelli (2011), who argues that the development of specific cognitive skills is directly related to the type of technological tools used in the classroom. According to this author, students better understand physical principles when they work with sensors, simulation environments, and graphical representations that allow them to interact with data.

The procedural dimension also reflected a significant transformation. Before the intervention, over 40% of students in the experimental group were at the initial level. After applying Matlab in the learning sessions, 84% reached the prior achievement level, 2% the distinguished level, and no students remained at the initial level. These results concur with the conclusions of Cabello (2012), who states that the use of Matlab enhances students' academic performance by impacting both cognitive aspects and their reasoning processes. The software not only provides a tool for solving problems but also fosters a methodology of systematic and logical thinking.

In terms of the communicative dimension, the evolution was equally significant. Before the intervention, 76% of students were at the progress level and 24% at the initial level. Subsequently, 86% reached the prior achievement level, 10% the distinguished level, and none remained at the lower levels. This result suggests that collaborative work, guided by the use of Matlab, favored not only conceptual understanding but also students' ability to communicate, argue, and transfer what they learned to new situations. In line with this, Ayala (2016) warns that often limited laboratory equipment restricts practical teaching, generating difficulties in professional training. The use of Matlab compensated for this limitation, as it allowed the recreation of experimental scenarios, simultaneously sparking students' interest in learning and expressing themselves through digital means.

These findings are also supported by Manazeda (2021), who demonstrated that Matlab significantly contributes to the development of problem-solving ability in kinematics, considering it an effective teaching resource. This empirical evidence coincides with reports by Mollinedo et al. (2017) and Cabrera (2018), who, through statistical tests such as Student's t-test and Z analysis, confirmed that the use of software positively and significantly influences the teaching-learning of complex physical content.

Furthermore, the study is strengthened by the findings of Calderón (2020), who created a GeoGebra model to illustrate the kinematic motion of a four-bar articulated mechanism. His work highlights the educational importance of simulators in reinforcing learning across various branches of Physics. In this specific study, Matlab was used similarly to facilitate the analysis of physical systems from a computational perspective; this contributed to students' understanding of kinematics and fluid dynamics, as well as thermodynamics and electrical circuits.

Additionally, Gañán (2020) indicates that employing educational technologies facilitates the transition from empirical knowledge to formal understanding. His research demonstrates how, through the use of virtual laboratories and systematic comparison with conventional methods, students manage to merge acquired knowledge with their daily lives, thereby favoring better content assimilation. In this analysis, an analogous process was observed: students not only completed exercises but were also able to establish connections between learned concepts and real-world phenomena.

In summary, the results obtained indicate that the use of Matlab not only improved academic performance but also transformed the way of learning by fostering a collaborative and reflective approach that aligns with the principles of meaningful learning. The incorporation of computational simulation in the training process provided a clearer representation of physical concepts and simultaneously offered the opportunity to develop essential cognitive and communicative skills for engineering education.

Conclusions

The results obtained during the investigation indicate that the use of Matlab in teaching Physics had a positive and relevant impact on the meaningful learning process of Engineering students at the National Agrarian University of La Selva. Quantitative results showed a considerable increase in average scores across all evaluated areas during the study. In the conceptual dimension, scores increased from 21.0 to 35.4 points between the pretest and posttest. In the procedural dimension, scores rose from 22.2 to 37.2 points. Finally, in the communicative dimension, scores improved from 18.9 to 31.8 points. Overall, the total score for meaningful learning increased from 62.1 to 104.4 points. These improvements were statistically significant and supported the effectiveness of the educational approach based on Matlab.

Moreover, it was determined that the use of Matlab greatly aided in enhancing cognitive abilities by simplifying the understanding of complex physical ideas through interactive simulations and laboratory visualizations. Students not only solved practical challenges but also acquired skills to represent and communicate their results more clearly and accurately. Additionally, the use of the program positively affected the achievement levels attained: before the intervention, initial and progress levels predominated, whereas after implementation, 90% of students in the experimental group were at the prior achievement level, 8% were in progress, and 2% achieved the distinguished level. This change demonstrated that the proposal not only improved student performance but also significantly transformed the learning experience.

It was evident that the level of meaningful learning in its three dimensions—conceptual, procedural, and communicative—was clearly superior in the experimental group compared to the control group, which showed no relevant changes. This confirms the importance of incorporating Matlab as an educational tool in teaching Physics.

During the structured sessions, the educational proposal was implemented, fostering collaboration among students under the guidance of instructors, along with the use of a rubric that allowed for constant evaluation of student progress. The pedagogical planning and detailed monitoring of the learning process contributed to strengthening knowledge in both theoretical and practical aspects.

Finally, it was confirmed that the incorporation of Matlab enriched the educational process by implementing an active approach centered on solving real problems and experimental analysis. This modality promoted deeper and more meaningful learning, fostering autonomy and meeting the demands of excellence in engineering professional training. Therefore, it is suggested to systematically include Matlab, or other similar simulation environments, in basic science programs as part of a comprehensive strategy for pedagogical innovation aimed at strengthening scientific thinking, problem-solving, and the development of skills for professional life.

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