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The development of theoretical thought in the teaching of physics: a proposal from the historical-cultural approach

O desenvolvimento do pensamento teórico no ensino de física: uma proposta a partir do enfoque histórico-cultural

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ABSTRACT
This article aims to explain a guiding scheme for the teaching and learning process of general physics, which enables the development of theoretical thinking in engineering students. The theoretical foundation is based on the Historical-Cultural Theory and uses, in particular, authors such as Vygotski (1996), Davídov (1981, 1988, 1999) and Galperin (1973) to understand the development of theoretical thinking and the principles for teaching to be developmental. The guiding scheme, proposed on the basis of theoretical and bibliographical studies, translates into an instrument that is effective with the active participation of students and groups in the construction of physics knowledge, appropriating the essential concepts and understanding the different objects of this science, which enables the construction of new meanings and theoretical thinking.

Keywords: Teaching and learning process; Physics teaching; Historical-Cultural Approach.

RESUMO
Este artigo objetiva explicar um esquema orientador para o processo de ensino e aprendizagem de física geral, que possibilite o desenvolvimento do pensamento teórico de estudantes de engenharia. A fundamentação teórica está pautada na Teoria Histórico-Cultural e se utiliza, em especial, de autores como Vygotski (1996), Davidov (1981, 1988, 1999) e Galperin (1973) para compreender o desenvolvimento do pensamento teórico e os princípios para que o ensino seja desenvolvimental. O esquema orientador, proposto a partir de estudos teórico-bibliográficos, se traduz em um instrumento que se efetiva com a participação ativa dos estudantes e grupo na construção do conhecimento de física, se apropriando dos conceitos essenciais e compreendendo os distintos objetos dessa ciência, o que possibilita a construção de novos significados e do pensamento teórico.

Palavras-chave: Processo de ensino e aprendizagem; Ensino de Física; Ensino Superior.

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1 Introduction

The development of theoretical thinking, a process studied and desired by the Historical-Cultural Approach (HCA), is directly related to the teaching and learning processes carried out in school education. As it is a process, it can be enhanced to a greater or lesser degree, depending on the tasks proposed and the mental actions mobilized by students to perform them.

Theoretical thinking (Davidov, 1991) is based on dialectical logic and aims to understand the relationships and connections present in the dynamics of reality. From this perspective, the teaching and learning process advocates enhancing students' mental development to overcome empirical thinking.

As pointed out by Cañedo (2013, 2022), Rodríguez (2014), and Moreira (2018), in universities, especially in the teaching of physics, the formal logic sustained by traditional schools still persists, which leads to a predominance of empirical thinking, generating deficiencies in the development of students' theoretical thinking. However, this does not mean that working with essences is not encouraged in some way and, consequently, to some extent, also contributes to the development of theoretical thinking, but not in a scientifically oriented manner.

The problem is that, because society has evolved so much, professionals are expected to perform at a high level. This means it's important to develop their theoretical thinking skills, and physics can contribute to that, along with other subjects. However, the methods used to achieve this may indirectly stimulate it while working with the content being taught, but they do not intentionally promote its formation and development.

With this in mind, we should ask: how can we encourage students to use theoretical thinking in their physics labs for engineering courses? This will help them apply the most important ideas in real-world situations and solve problems more effectively.

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To this end, this article applies a didactic concept through the use of tools aimed at creating situations that enhance the zone of proximal development for the development of theoretical thinking. Theoretical (complex-dialectical) thinking is also defined in the form of a construction, based on the reading of Davidov (1981) and Leon (2019), and the guiding basis of type III actions (GALPERIN, 1973).

It should be clarified that the guiding basis for type III actions, proposed by Galperin (1973), is a theoretical model based on principles that guide the development of actions aimed at developing mental actions involving the resolution of new and complex problems.

In this sense, the objective of this article is to explain a guiding framework for teaching general physics in laboratory classes, which guides the search for the essence of the object of study, showing it in its genesis and evolution, in order to favor the development of theoretical thinking in engineering students.

It is argued that physics can be a conducive medium for the development of theoretical thinking, if conditions are created for students to construct their knowledge through help, forming a guiding basis for type III actions (GALPERIN, 1973), once the intended concepts are not given, by applying the method of ascending from the abstract to the concrete (DAVIDOV, 1991).

This work is based on a philosophical position called dialectical materialism. It assumes that EHC is a psychological foundation for understanding the complexity of physics teaching and learning, especially in laboratory classes. People develop in a social environment, and each person's journey is different. Education should give students the tools they need to grow. When it's time for people to evolve, it's important to support their development.

Education is the process by which society's rules are learned and applied to each person's life. This learning happens through the internalization of social norms, influenced by the individual's personal development and the support of their peers and community.

Based on the above, a guiding framework for the teaching and learning of physics in laboratory classes for engineering students was designed, based on

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theoretical and bibliographic studies, such as Davidov (1981), Leon (2019), and Galperin (1973). In the following section, the guiding framework and explanations for its design will be presented.

2 General guidelines for teaching general physics to engineering students

The suggested design of the guiding framework is based on categories that interrelate to promote generalizing abstraction, essential analysis, and integrative synthesis of properties conveyed by the meaning of the word, to support your thinking in the development of concepts following the method of ascending from abstract to concrete thinking.

According to Davidov (1988, p. 141), "the theoretical reproduction of concrete reality as a unity of diversity is achieved through the process of ascending from the abstract to the concrete." Theoretical thinking is complex in essence because it emanates from dialectical-materialist philosophy, which sees everything as interrelated and concatenated. It strengthens critical thinking because it offers the possibility of working with the genesis, essences, and essential connections of the object, which gives it greater solidity and depth in the issuance of criteria and value judgments. It favors the emergence of creativity, once the relationship between the general, the particular, and the singular has been established, which allows it to apply the essences and essential connections of the object to particular and singular cases.

For Davidov (1999), theoretical thinking supports a certain attitude toward the knowledge of reality, which is expressed in the subject's ability to solve the daily tasks of life, with the dialectical combination of the abstract and the concrete (practical).

Davidov (1981) states that among the foundations of theoretical thinking is mental experimentation, which operates through scientific concepts, causing the subject to mentally attribute one interaction or another to objects, a dialectical interrelation seen as a totality, a certain form of movement.

The construction and application of Type III Guiding Bases for Action (BOA), from Galperin's theory (1973), is what enables the formation of theoretical thinking, since it has the following characteristics: integration between knowledge and science;

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essential synthesis; realization of essential generalization in relation to the content studied; analytical orientation; and abstraction of the essential transcending the phenomenal, the concrete, and the empirical. Without losing the dialectical relationship between the general and the particular in the analysis, in order to recognize the natural complexity of the object of study, which will be seen in the formation.

During the construction of knowledge, group work promotes the formation of active learning that fosters values such as independence, responsibility, solidarity, effort, and scientific rigor—values that respond to the model of man we want to form. Here, pedagogy and didactics are integrated by showing how students' theoretical thinking is formed through a didactic resource: the guiding framework.

Valdés et al. (1999) propose a series of steps for the formation of the concept of physical magnitude, establishing relationships between properties and magnitudes, which contributes to theoretical thinking and to finding meaning and significance for the contents of this science.

The sequence of steps proposed by Valdés et al. (1999) includes, first, demonstrating in practice the existence of the property to be characterized quantitatively. Next, demonstrating in practice that not all objects exhibit the same degree or form of the object in question. Then, defining the procedures for associating a quantity with the object under study. Finally, demonstrate the validity of the established concept. Other authors also discuss concept formation in physics, such as Lago, Ortega, and Mattos (2018).

To this effect, it is necessary to structure the content, supported by a cell of understanding, within a guiding framework that integrates the diverse with the unique, essential, and therefore general. With the construction of knowledge following the method of ascending from the abstract to the concrete, the interrelation-structuring-systematization of the object of study will be achieved and the formation of theoretical thinking will be enhanced (Cañedo, Zanelato, and Douglas, 2019), (Campelo, 2003), (Bernardes, 2016), and (Santos, 2018).

Physics provides students with scientific methods and guides them in the formation of sensory-objective-cognitive actions linked to nature. It can form skills

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and abilities for theoretical thinking depending on how the process materializes to allow the perception of what is not explicitly given in nature: the functions of the structural components of the property of the object of study.

Theoretical thinking reflects the facts that may be possible, crystallizing them and making them real in order to discover the "qualitative boundary between the content of sensory reality and that of theoretical thinking" (Davidov, 1981, p. 325). As stated:

> [...] Thought often develops its activity when the actual development of the object has already taken place [...] it can anticipate "nature" and perceive in industry what in "nature" is only a possibility [...]. The conditions for its transformation into reality are fully found by thought [...] theoretical thought does this with what crystallizes as possible, and thanks to which this possibility becomes reality. (Davidov, 1981, p. 325).

For this to be possible in physics laboratory classes, a coherent and theoretically grounded teaching plan is necessary. The proposal of a guiding framework as a teaching method and instrument, a specific tool for learning this science with the aim of forming a way of thinking that is essential for engineers to fulfill their social task.

The framework that guides the process of teaching and learning physics will be presented in topics, namely: 1. Characterization and analytical description; 2. Problematization; 3. Formulation of hypotheses; 4. Essential analysis, symbolization, and assignment of units; 5. Execution of work (Measures); 6. Recording and tabulation of data; 7. Modeling and synthesis; 8. Applications and experimental planning; 9. Evaluation and control.

1. Characterization and analytical description

Analytical characterization and description through argumentation and focused attention from the outset are necessary to accurately represent the physical situation you are facing. This is in addition to identifying the conditions, properties, and units of measurement.

It is necessary to argue and determine the essential and phenomenal characteristics of the observed physical fact. Establish the relationship between

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the object of study and its applications in science, technology, and society. In the context of your scientific education and the contribution of the media to your previous scientific training, take into account the information and culture accumulated by the student in their life history, in their prior knowledge, and in their prejudices (or everyday concepts) as a starting point, to problematize and introduce the topic and object of study through the laboratory.

It is important to relate the laboratory and the content of the experiment to be carried out to the future profession, so that it contributes to the construction of its meanings and signifiers, which are achieved when the objectives of the activity coincide with the needs.

The student first encounters the physical fact, which will be the object of study, from which he must uncover its essence in order to promote the formation of his theoretical thinking. The important thing for the formation and development of this type of thinking is not to remain in the study of the fact for the sake of the fact, which helps what is concrete and directly perceptible by the senses to be part of the content of thought, as this is what fosters empiricism and the thinking that derives from it.

It is based on action upon the object in order to understand it, on the study of the conditions that give rise to it, and on the historical-genetic analysis that makes it scientific. This makes it possible to transform it by finding its essence, explaining the procedures in the construction of knowledge, the causes and consequences of the different phenomena under study, the creativity of the subjects based on the definition of theoretical concepts, and establishing the scientific bases of theoretical thinking as a reflection of the dialectic of the object. The relationship between properties, magnitudes, and units is identified as the central cell and unit of analysis for the construction and understanding of physical knowledge and the formation of theoretical thinking.

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2. Problematization

This moment should be used to illustrate applications of the phenomenon being studied, to raise students' awareness of the missions and functions of science in society, which should be included in the problem through questions, and to discover contradictions during the problematization. As well as raising awareness through argumentation, expressing doubts as a result of their observations. A study of possible expectations and predictions of results should be carried out. It is the process in which essential and non-essential characteristics meet to make the known and the unknown conscious, and establish their relationships. Become aware of the expected and the unexpected through argumentation and cognitive conflicts derived from the physical facts under study and their details.

From the student's point of view in the orientation phase, they must identify that the statement of the problem represents an application of the object of study, which, given certain particular and general conditions that allow its existence, engenders a certain contradiction between the known and the unknown.

3. Formulation of hypothesis

The problems are proposed by the students, and possible answers are given to questions, contradictions, and cognitive conflicts, their possible solutions, discovering the relationships that may exist between properties, which are expressed by their respective magnitudes, expectations are revealed, and arguments are introduced, presenting the reasonings that lead them to such positions.

Hypotheses are also proposed in the planning of experiments, based on the induction of research needs. The professor is not a master, but offers them levels of help depending on their zones of proximal development at a given moment.

They cease to be the tutor, the main executor, the organizer, the structurer, the illustrator of the content, and become the guide, the driver, the observer, the promoter, the facilitator, the motivator, the controller, the clarifier, and the evaluator of the students' learning process.

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With this methodology, in all types of classes, reproductive tasks that induce passivity in students are replaced by tasks that stimulate research, elaboration, complex analysis, problematization, hypothesis development, integration, creation, discernment, resolution, modeling, self-evaluation, and co-evaluation, which favor active behavior.

4. Essential analysis, symbolization, and assignment of units

The physical fact (which serves as a demonstration) is observed, expressing its properties and the relationships between them. Students must be able to use analytical abstraction to identify these properties and their relationships and then express them through their arguments, which they discuss with the professor and other students in the team.

Once the properties have been identified, each one is assigned a quantity that symbolizes it, using a sign. The meaning of the symbol represents and expresses the degree to which the property manifests itself, which can be quantified using the unit of measurement. This allows a value to be assigned when the measurement is made on the physical event observed during the experiment.

Next, it is necessary to determine the unit, the smallest quantity in the set, the smallest standardized quantity of the property that can be determined without ceasing to exist as such, and in accordance with the possibilities of the level of precision of the measuring instruments available for measurement, that is, the comparison with another property quantified and calibrated in an instrument.

In this way, it is possible to determine how many times the smallest quantity of a quantified property is found in the experiment through the number of times the unit of measurement that represents it appears, and thus the degree to which that property is expressed can be counted. In this way, a measure of its value is determined through quantity, which allows analyzing and finding relationships between properties through the values of the quantities obtained in the measurements of the phenomenon.

They must specify and distinguish between simple and complex properties in order to determine the corresponding simple and complex quantities and units.

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Simple properties are the essential characteristics of the object of study that appear immediately and are independent of other properties.

Complex properties are those that are configured through a certain relationship between several properties, so that they can be integrated and become a property that may be new, unique, or unrepeatable only for the observed phenomenon, in order to identify, characterize, determine, and define it; therefore, it is unique to a concrete phenomenon and allows the essential generalization to be made, to elaborate the law that characterizes it.

The property-magnitude-unit of measurement relationship as a cell is embedded in the conceptual fabric of law and principle and is therefore the central unit of analysis for the construction of physical knowledge, understanding, and the formation of theoretical thought.

5. Execution of work (Measures)

The first thing to consider is the correct procedures for carrying out the activity. The measurement is then performed by comparison, using the appropriate instruments. The next step is to determine the uncertainties of the collected data. Avoid errors in measurements, adopt the correct posture during measurements, and ensure the accuracy and precision of the measurements.

It is also important to know how to use the measuring equipment in the experimental project. Students must explain and argue to demonstrate that they are prepared to perform the activity. Using the instruments and resources at their disposal, both mathematically and physically, with the data values, according to the representation of the problem, they must develop a strategy that allows them to find the possible path or paths to solve it.

6. Recording and tabulation of data

The data is collected by filling out the corresponding data collection tables, which include the measurement values and the students' observations on the experiment.

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7. Modeling and synthesis

Graphical modeling consists of producing graphs to obtain the mathematical function that relates the dependent variable to the independent variable, and that allows the relationships between them to be established, using the values obtained in the measurements taken.

Modeling is a process by which the mathematical expression that defines the observed physical fact (the semiotic model) is generated, in which the relationships between all quantities appear, which is nothing more than the expression of the connections between all the characteristic properties of the object of study, in order to obtain the law that defines it.

In this process, the connections between quantities are found to be an essential property, as it is a unique configuration that allows us to show the essential connections between the properties of the phenomenon through their magnitudes, to be integrated synthetically into a complex property that characterizes the physical fact observed in the experiment.

This makes it possible to discover the concepts, laws, and principles that govern and enable us to explain, predict, transform, and apply the laws of the object of study to certain situations in science, technology, and society. All of this must be explained and expressed by the students in the group to the professor, who must listen to their arguments to ensure that the students have mastered and understood them.

8. Applications and experimental planning

Based on the process carried out, the student proposes an experimental design to verify the law that has been discovered, which must be different from the experiment carried out. The feasibility is discussed and verified, and the reasons for raising the student's awareness of the proposal are discussed. The application of the knowledge learned in a technical-scientific situation is proposed, developing an engineering problem.

This reveals the role of theoretical thinking in the design and execution of the experiment as part of the process of seeking an answer to a problem in science,

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or in its historically determined sociocultural context. In this process, students must give meaning to concepts, find personal significance in this knowledge; that is, it must represent something to them.

The need for students to establish the relationship between the meaning and significance of the knowledge they acquire about physics, based on the appropriate use of the symbolic language of the discipline, in order to understand the different objects of study of this science and influence the formation of the personality of the future professional (Douglas, 2007), is transcendental in the process of teaching and learning physics.

This means that great importance should be given to the moment when the student is able to understand what is expressed by the relationship between the properties, magnitudes, and units of the object of study in question, in the physical interpretation of laws, equations, and principles when integrating all components.

This occurs in the transfer of mathematical language to the physical context, insofar as implications are assumed that do not disregard the general and abstract meaning of mathematical language applied to physical situations, which are a more particular and concrete field, so that physical meaning can be given to the symbolic language of mathematics in physics and what has been learned can be applied.

In this way, stereotypes and blind operationalism, simplistic and empirical thinking are avoided, without forgetting that there are also physical situations transferred to mathematical language in which the opposite path is followed. The goal is to prevent and avoid the problem posed by Talízina (1985, p. 15):

> A more serious problem that arises in sciences such as physics, especially theoretical physics, is that the mathematical model is sometimes so far removed from physical reality that the student, when performing all the mathematical operations, sees no physical meaning or significance behind it and cannot practically interpret what they have obtained. This is a problem.

This proposal aims to overcome this problem by allowing students to establish the relationship between the meaning and significance of the knowledge they acquire about physics and their future profession.

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9. Evaluation and control

Students write a report consisting of a theoretical summary, a description of the experimental project, a list of questions and problems developed, the hypotheses presented, the objectives of the activity, and the relationship between properties, magnitudes, and units.

In the control phase, once the solution to the problem has been found, it is verified whether the numerical value is adequate and logical, whether the units in which the answer is given are consistent, whether feedback is given, and whether the operations and steps performed are reviewed to verify that there was no procedural error and to ensure that they are adequate to solve the problem, as a particular or singular case.

Assessment is conceived as the possibility of verifying the development of the skills achieved by the student, together with the appropriation of knowledge, without being punitive. Assessment moments are milestones where the student sets new goals and objectives, accepting error as a natural part of the learning process that generates new forms of effort. It is encouraged to be carried out by the professor, by some students in conjunction with other students, and by the student themselves.

Throughout the process, assessment is systemic, predictive, and procedural. From the beginning of the physics course, students are made aware of the indicators of theoretical thinking that will be taken into account in the assessment of the discipline, so that they can serve as a guide for self-assessment and self-orientation of learning.

To assess knowledge formation, a guidance manual is used to support the orientation, execution, and control of problem-solving, laboratory work, and theoretical presentations. A group evaluation of the process and overall results of the work is also conducted.

The control, feedback, diagnosis, and evaluation system occurs throughout the process, although sometimes one action or another predominates, as the professor must constantly diagnose the student's actual zone of development and their zone of proximal development in order to guide them to higher levels of development. At the same time, they must provide feedback on their teaching process and encourage student feedback on their learning process, explaining the difficulties, obstacles, barriers, and achievements they are experiencing.

It is therefore necessary to monitor what the professor does and what the student does, the activities that are carried out, and the quality that is achieved, all in relation to a previously established model. The guidance system allows for the identification of strengths and weaknesses, shortcomings, and deficiencies in the process.

3 Final considerations

The focus of this article is to explain the proposed framework to guide the process of teaching and learning physics for engineering students. The framework was created to guide the didactic work of ascending from the abstract to the concrete, seeking the essence of the object of study, showing it in its genesis and evolution, to favor the development of theoretical thinking in engineering students.

The framework is based on a didactic conception of physics for the development of theoretical thinking in engineering students, and guides the teacher's actions for the formation and development of this type of thinking.

It is necessary to take into account the didactic cell in the application of the method of ascending from abstract to concrete thinking in the teaching and learning of physics, fulfilling certain requirements through the use of the guiding framework in active teaching situations, to promote the development of theoretical thinking.

The guiding framework as a means of teaching in physics laboratory classes was designed to fulfill an invariant systemic structural function, since it was developed taking into account the fundamental component categories that make up the process of constructing and understanding physical knowledge, and serves as support in guiding theoretical thinking in the execution of its actions, in the construction of knowledge, which is why this framework favors the formation and development of this type of thinking.

The framework includes the cell that generates physical knowledge: the property-magnitude-unit of measurement relationship as interconnected primary

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categories. It is a tool for learning during study activities, as it guides students' thinking in the search for the essential relationships of the phenomenon, which is vital for understanding and problem-solving.

Physical equations are an integration of different cells, that is, the interconnection between various property-magnitude-unit interrelationships, which form a "fabric" to construct the physical meaning that gives rise to a new property, a new concept, different but derived from the object of study, which has to do with the meaning of these cells separately, since, when they integrate, each of these interrelationships is configured and contributes to conceptualization, expressing itself in the complexity of the object of study investigated, in its laws, equations, principles, axioms, and postulates. This allows students to construct appropriate scientific meanings.

This allows the student and professor to adopt a systemic approach to detect and understand processes. Once the essential relationships are known, the necessary understanding is achieved to apply this knowledge to particular cases in problem-solving.

Further studies and research on the current guidance system are needed. It needs to be tested in different contexts of physics laboratory classes and kept under improvement so that it fulfills its function.

El desarrollo del pensamiento teórico en la enseñanza de la física: una propuesta desde el enfoque histórico-cultural

RESUMEN
El objetivo de este artículo es explicar un esquema orientador para el proceso de enseñanza y aprendizaje de la física general, que permita el desarrollo del pensamiento teórico en los estudiantes de ingeniería. La fundamentación teórica se basa en la Teoría Histórico-Cultural y utiliza, en particular, autores como Vygotski (1996), Davidov (1981, 1988, 1999) y Galperin (1973) para comprender el desarrollo del pensamiento teórico y los principios para que la enseñanza sea desarrolladora. El esquema orientador, propuesto a partir de estudios teóricos-bibliográficos, se traduce en un instrumento eficaz con la participación activa de los alumnos y del grupo en la construcción del conocimiento de la Física, apropiándose de los conceptos esenciales y comprendiendo los diferentes objetos de esta ciencia, lo que posibilita la construcción de nuevos significados y del pensamiento teórico.

Palabras clave: Proceso de enseñanza y aprendizaje; Enseñanza de la Física; Enseñanza superior.

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