AN EXPERIMENTAL APPROACH TO TEACHING GAUSS'S LAW IN INITIAL PHYSICS TEACHER EDUCATION

UMA ABORDAGEM EXPERIMENTAL PARA O ENSINO DA LEI DE GAUSS NA FORMAÇÃO INICIAL DE PROFESSORES DE FÍSICA

UN ENFOQUE EXPERIMENTAL PARA LA ENSEÑANZA DE LA LEY DE GAUSS EN LA FORMACIÓN INICIAL DE PROFESORES DE FÍSICA

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ABSTRACT

This study presents an experimental approach to teaching Gauss's Law in undergraduate physics education. The proposal is based on a research-oriented didactic model that integrates experimentation, language, and knowledge construction. The methodology consisted of designing and implementing a sequence of activities using conductive paper to simulate a coaxial cable system, allowing the analysis of electric field and electric flux. The results showed that 70% of the students achieved a satisfactory level of conceptual understanding, indicating the effectiveness of the experimental approach in learning electromagnetism. It is concluded that the integration of theory and experimentation significantly contributes to the conceptual understanding of Gauss's Law.

Keywords: Gauss's Law. Physics Education. Experimental Learning. Electric Field. Electromagnetism.

RESUMO

Este estudo apresenta uma proposta de ensino da Lei de Gauss baseada em uma abordagem experimental aplicada a estudantes da Licenciatura em Física. O trabalho fundamenta-se em um modelo didático orientado à pesquisa, que integra experimentação, linguagem e construção do conhecimento. A metodologia consistiu na elaboração e implementação de uma sequência de atividades experimentais utilizando papel condutor, simulando um sistema análogo a um cabo coaxial, o que possibilitou a análise do campo elétrico e do fluxo elétrico. Os resultados indicaram que 70% dos estudantes alcançaram compreensão satisfatória dos conceitos envolvidos, evidenciando a eficácia da abordagem experimental no processo de aprendizagem em eletromagnetismo. Conclui-se que a integração entre experiência e teoria contribui significativamente para a construção conceitual da Lei de Gauss.

Palavras-chave: Lei de Gauss. Ensino de Física. Experimentação. Campo Elétrico. Eletromagnetismo.

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RESUMEN
Este estudio presenta una propuesta de enseñanza de la Ley de Gauss basada en un enfoque experimental aplicado a estudiantes de la Licenciatura en Física. El trabajo se fundamenta en un modelo didáctico orientado a la investigación, que integra la experimentación, el lenguaje y la construcción del conocimiento. La metodología consistió en la elaboración e implementación de una secuencia de actividades experimentales utilizando papel conductor, simulando un sistema análogo a un cable coaxial, lo que permitió el análisis del campo eléctrico y del flujo eléctrico. Los resultados indicaron que el 70% de los estudiantes alcanzó una comprensión satisfactoria de los conceptos involucrados, evidenciando la eficacia del enfoque experimental en el proceso de aprendizaje del electromagnetismo. Se concluye que la integración entre la experiencia y la teoría contribuye significativamente a la construcción conceptual de la Ley de Gauss.

Palabras clave: Ley de Gauss. Enseñanza de la Física. Experimentación. Campo Eléctrico. Electromagnetismo.

1 INTRODUCTION

This article presents a study on the teaching of Gauss's Law from an experimental approach, with the objective of favoring the construction of concepts by students of the third semester of the Physics Degree at the Federal Institute of Brasília.

The literature review showed a scarcity of studies that address the experimental dimension of Gauss's Law. In this sense, it is relevant to propose a contribution that values experimentation, considering the close relationship between experience, language and knowledge (Arcá et al., 1990).

In this work, we propose an investigation that has experimentation as a basis for the construction of knowledge. The proposal consists of approaching Gauss's Law through a process that highlights the need to understand electromagnetic phenomena, articulating theory and practice.

For the development of the proposal, a research-oriented didactic model was adopted, in which students are encouraged to investigate problems in a similar way to scientific practice. It is noteworthy that scientific activity does not follow a rigid method, but has widely accepted characteristics, such as its social character, the role of divergent thinking and the rejection of an empiricist view based exclusively on isolated data (UNESCO, 2005).

The proposed learning sequence includes the presentation of open problem situations, the performance of qualitative analyses, the development of experimental strategies and the collective discussion of the results. In this way, it seeks to favor the construction of scientific knowledge through the active participation of students.

Based on these considerations, the learning sequence was elaborated and implemented with the objective of analyzing its contribution to the understanding of Gauss's Law, based on learning indicators defined for this purpose.

2 FORMULATION OF THE PROBLEM

One of the objectives of the Federal Institute of Brasília is the development of alternative models for the training of teachers in experimental sciences. In this context, the importance of proposals that consider experimental activity as a fundamental element in the construction of knowledge is highlighted.

Thus, this work proposes the development of an alternative approach to the teaching of Gauss's Law, based on experimentation, allowing students to understand this law both from experience and theory.

To support this proposal, the cognitive process model presented by Arcá, Guidoni and Mazalli (1990) is adopted, which establishes an inseparable relationship between language,

experience and knowledge. These three elements are considered equally important and interdependent, and there is no hierarchy between them.

However, in many teaching situations, students are presented only with the equations of Gauss's Law, without a clear connection to the experience that underlies these concepts. This approach can make it difficult to build meaningful understanding, as it disregards the relationship between language, experience, and knowledge.

Therefore, this research seeks to contribute to students to build their own ideas about Gauss's Law, through a sequence of experimental activities that stimulate reflection on the need for this law in the study of electromagnetic phenomena.

As a starting point, it is considered that students already have previous knowledge about Coulomb's Law, which allows them to problematize questions such as: what are the limitations of this law? In what situations can it be applied? How to describe electric fields in continuous load distributions?

In this context, it is understood that the difficulty in understanding Gauss's Law is related, to a large extent, to the way it is introduced in teaching, generally detached from its experimental basis.

2.1 RESEARCH QUESTION

In view of the above, the following research question is formulated:

How to present Gauss's Law to undergraduate students in Physics through a process that highlights its necessity in the study of electromagnetic phenomena?

3 RESEARCH PROBLEM AND THEORETICAL FOUNDATION

Many university students have difficulties in solving problems related to electromagnetism, even after being exposed to similar content in the classroom. Studies indicate that students who have taken courses such as Electromagnetism I and II often do not develop an adequate understanding of field theory, unaware of its scope and limitations.

A possible explanation for this difficulty lies in the way the contents are presented. In many cases, physical laws are introduced in a predominantly operational way, without in-depth reflection on their meanings and without an explicit connection to the experience that gives rise to them. In addition, a relationship is rarely established between theoretical concepts and the measuring instruments used in practice.

Specifically in the case of Gauss's Law, it is observed that its teaching is often decontextualized. Often, it is presented only as an equation for calculating the electric field, without exploring the experimental basis on which its formulation is based. In general,

teaching begins with Coulomb's Law, applicable to point loads and static fields, which can limit students' understanding of the need for a more general approach, such as that provided by Gauss's Law.

In this context, the students' difficulty in understanding Gauss's Law is largely related to the absence of experiences that allow them to construct meaning for the concepts involved. Thus, students are often exposed to equations without fully understanding their physical interpretation.

In view of this, it is necessary to rethink the way this law is taught, incorporating approaches that integrate theory and experimentation.

From a theoretical point of view, this work is based on the conception that scientific knowledge is constructed from the interaction between language, experience and knowledge (Arcá, Guidoni & Mazalli, 1990). These three elements are interdependent and essential for understanding physical phenomena.

In addition, studies show that students arrive in the classroom with previous conceptions that influence their interpretations of the phenomena (Driver, 1987), reinforcing the importance of teaching strategies that promote active participation and the construction of hypotheses.

In this sense, experimentation plays a fundamental role, as it allows the student to relate theoretical concepts to real situations. As highlighted by Duschl (1997), the teaching of science must contemplate both the context of justification and the context of discovery, the latter being essential for the development of scientific thinking.

Thus, the present work proposes an experimental approach as a strategy to favor the understanding of Gauss's Law, considering that the integration between theory and experience is essential for the construction of knowledge in Physics.

3.1 SPECIFIC OBJECTIVES

- Design a didactic experiment that enables students to understand phenomena whose analysis involves Gauss's Law;
- Develop and implement a sequence of activities that integrates conceptual and procedural aspects;
- Analyze learning outcomes based on indicators defined for this purpose.

4 METHODOLOGY

The present research is characterized as descriptive, with a qualitative approach, with the objective of analyzing the processes of conceptual construction of students in the

understanding of Gauss's Law. This type of research is widely used in the educational area, as it allows the observation and interpretation of phenomena related to the cognitive development of students (Cohen & Manion, 1989).

The study was carried out with students of the Physics Degree course at the Federal Institute of Brasília, in the context of the discipline of Electromagnetism. The methodological proposal was based on the application of an investigation-oriented didactic sequence, in which students were led to explore physical concepts through experimentation.

4.1 EXPERIMENT DESCRIPTION

For the development of the proposal, a didactic experiment called *coaxial cable was used*, adapted from Ludwigsen (2006). The experiment consists of a conductive paper containing two concentric circular electrodes, which allow simulating the distribution of the electric field in a system analogous to a coaxial cable.

From this configuration, students were able to investigate concepts such as electric field, electric potential, and electric flow, establishing relationships between experimental measurements and theoretical models.

4.2 MATERIALS USED

- Digital multimeter
- Voltage supply (0–10 V)
- Alligator-alligator cables
- Styrofoam sheet (35 × 25 × 1.5 cm)
- Conductive paper with concentric electrodes (disc and ring)
- Metal pins for electrical connection

4.3 TRIAL ASSEMBLY

The conductive paper was fixed on the Styrofoam base. Then, metal pins were inserted into the central and external electrodes, ensuring electrical contact. These pins were connected to the voltage source by means of cables, establishing a potential difference between the electrodes.

4.4 SEQUENCE OF EXPERIMENTAL ACTIVITIES

The didactic sequence was organized into three main moments, called interventions.

4.4.1 Intervention 1 – Measurements of electric potential

In this stage, the students used the multimeter as a voltmeter to measure the potential difference between points on the conducting paper.

Measurements were performed at different radial positions (e.g., r = 4 cm, 6 cm, and 7 cm), allowing the ratio between the potential difference and the distance between the measured points to be calculated. These values were recorded in a table and analyzed by the students.

The objective of this activity was to lead students to identify the physical meaning of the ratio between potential difference and distance, associating it with the electric field.

Next, a tension meter with a fixed distance between tips (1 cm) was used, allowing direct measurements in units of V/cm. The students were instructed to compare the results obtained by different methods, establishing relationships between the measured values.

4.4.2 Intervention 2 – Direction of the electric field

In this stage, the students investigated the direction of the electric field through measurements at different points around the electrodes.

Keeping one of the tips of the instrument fixed, the other was moved around the system, allowing variations in measurements to be observed. The results were recorded and represented by vectors, indicating the direction of the electric field.

The objective was to promote the understanding of the orientation of the electric field and its relationship with the distribution of loads in the system.

4.4.3 Intervention 3 – Electrical flow

In the final stage, the students were led to relate the experiment to a three-dimensional model, considering the extension of the cylinder-shaped electrodes.

From this analogy, the characteristics of a Gaussian surface suitable for the calculation of electric flow were discussed. This activity aimed to introduce the concept of flow and its relationship with Gauss's Law.

4.5 DATA COLLECTION AND ANALYSIS

Data were collected through measurements made by students and answers to the questions proposed throughout the didactic sequence.

The analysis was conducted based on learning indicators, allowing to assess the level of conceptual understanding of the students in relation to the concepts of electric field, electric potential and electric flow.

5 RESULTS AND DISCUSSION

The analysis of the results aimed to identify the conceptual construction of the students throughout the learning sequence about Gauss's Law. For this, learning indicators specifically designed to evaluate the scope of the proposal were used, and these indicators were applied in a transversal way to the activities developed.

In order to systematize the analysis, three performance levels were defined, associated with the following categories:

- **Category A:** satisfactory understanding of the concept
- **Category B:** average understanding of the concept
- **Category C:** low understanding of the concept

This classification was adopted with the objective of facilitating the interpretation of the data and evaluating the effectiveness of the learning sequence, without the intention of reducing the complexity of the students' cognitive processes.

5.1 ANALYSIS OF PREVIOUS IDEAS

The learning sequence began with the following question: *"How to determine the direction of the electric field generated by two concentric electrodes?"*

The students answered that, although there is a theoretical and mathematical relationship to determine the direction of the electric field, they had no experience with its experimental determination.

This result evidences the absence of a previous experimental approach, reinforcing the need for the proposal developed in this work.

5.2 ANALYSIS OF INTERVENTION 1

In this step, the learning indicator related to the understanding that the voltage meter allows determining the electric field through the relationship between potential difference and distance was used.

Multimeter Usage

The students performed potential difference measurements at different positions and calculated the ratio between voltage and distance. When asked about the physical meaning of this relationship, they answered that it was a measurement associated with tension per unit length.

This answer was classified in Category A, as it demonstrates adequate understanding of the relationship between electric potential and electric field.

Usage of Tension Meter

In the next step, the students used a device that allows them to directly measure values in V/cm. When asked about the physical meaning of these measurements, they presented partially correct answers, indicating an understanding that is still developing.

This answer was classified in Category B, as it presents a conceptual approximation, although without total clarity.

When asked about the relationship between the data obtained from the different tables, the students presented answers that did not explicitly establish this connection, and were classified in Category C.

5.3 ANALYSIS OF INTERVENTION 2

In this stage, the students took measurements at different points in the system, with the objective of analyzing the direction of the electric field.

When asked about the measured physical quantity, the students recognized its relationship with the electric field, being classified in **Category B**.

Regarding the meaning of the negative sign in the measurements, the students correctly identified its relationship with the direction of the electric field, being classified in **Category A**.

In addition, by representing the results by means of arrows indicating the direction of the electric field, they demonstrated adequate understanding of the phenomenon, being classified again in **Category A**.

5.4 ANALYSIS OF THE CONCEPT OF ELECTRIC FLOW

In the final stage, the students analyzed the relationship between the experiment and a coaxial cable model.

By identifying the similarities between the configurations and by correctly describing an adequate Gaussian surface (cylindrical), they demonstrated a satisfactory understanding of the concept of electric flow, being classified in **Category A**.

5.5 GENERAL ANALYSIS OF THE RESULTS

The global analysis of the data was carried out based on the distribution of the answers in the defined categories.

The results indicated:

- **70%** of responses in Category A
- **12%** in Category B

- **18%** in Category C

These data show that most students achieved a satisfactory understanding of the concepts involved, indicating the effectiveness of the proposed experimental approach.

The results suggest that the learning sequence contributed significantly to the conceptual construction of the students, especially with regard to the understanding of the electric field, electric flow and Gauss's Law.

6 CONCLUSION

The results obtained in this study show that the proposed experimental approach contributed significantly to the conceptual construction of the students in relation to Gauss's Law. The implementation of the learning sequence enabled students to establish relationships between theoretical concepts and their experimental basis, overcoming difficulties previously identified in the teaching of electromagnetism.

It was observed that, initially, the students had limitations in the understanding of fundamental concepts, such as electric field, electric potential and their forms of measurement. However, after carrying out the experimental activities, it was possible to identify advances in the understanding of these concepts, especially in the recognition of the relationship between potential difference and electric field, as well as in the interpretation of the field direction.

In addition, the results indicate that most students achieved satisfactory levels of comprehension, as evidenced by the predominance of answers classified in category A. This result reinforces the effectiveness of the didactic sequence and highlights the role of experimentation as a central element in the meaningful learning of abstract concepts.

Thus, it is concluded that the integration between theory and experimentation constitutes an effective pedagogical strategy for the teaching of Gauss's Law, contributing to the formation of more critical Physics teachers capable of establishing connections between theoretical models and physical phenomena.

Finally, it is highlighted that the proposal presented can serve as a reference for the development of pedagogical practices in the teaching of electromagnetism, encouraging the adoption of investigative and experimental approaches in the teaching of Physics.

REFERENCES

Arcá, M. (n.d.). O desenvolvimento do processo cognitivo como tarefa da educação.

Arcá, M., Guidoni, P., & Mazalli, P. (1990). Ensine ciência.

Escritório Regional de Educação da UNESCO. (2005). Como promover o interesse pela cultura científica. Andros Printers.

Poincaré, H. (1904). O valor da ciência. Em H. Poincaré, La valeur de la science (pp. 189–215). Contraponto.

Driver, R. (1987, setembro 23–25). Uma abordagem construtivista para o desenvolvimento do currículo de ciências. Apresentação em evento, Valência, Espanha.

Duschl, R. A. (1997). Renovar o ensino da ciência. Edições Narcea.

Asenjo, O. R. (1990). Sobre o ensino de física. Sala de Aula Aberta, 7.

Cohen, L., & Manion, L. (1989). Métodos de pesquisa educacional. The Wall.

Ludwigsen, D. O., & Hassold, G. N. (2006). Uma sonda de campo elétrico simples em um laboratório de leis de Gauss. Aparelhos para o Ensino de Física, 4.

Halliday, D., & Resnick, R. (1961). Física para estudantes de ciências e engenharia. John Wiley & Sons.