Students' understanding of the physicochemical concepts of substance, properties, and transformations

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ABSTRACT
The teaching of Physics and Chemistry at the secondary level plays a crucial role in the cognitive development and critical formation of students, providing them with a solid understanding of the scientific foundations that permeate the world around them. This article aims to analyze the previous knowledge and degree of understanding of students in the first year of high school in relation to fundamental concepts of Physics and Chemistry, which were introduced in the ninth year of elementary school and deepened in the first year of high school. This research took place in August 2023 involving 120 students from the 1st year of high school who were present, through an extension activity applied in a public school in the municipality of Cuité in the state of Paraíba. In this study, it was observed that a considerable portion of students face significant challenges when interpreting the fundamental concepts of Physics and Chemistry. This difficulty can be attributed to a number of factors, ranging from the intrinsic complexity of these concepts to the pedagogical approaches employed in classrooms.

Keywords: Conception of students, Physicochemical concepts, Property of matter.

1 INTRODUCTION

The teaching of Physics and Chemistry at the secondary level plays a crucial role in the cognitive development and critical formation of students, providing them with a solid understanding of the scientific foundations that permeate the world around them. Within this context, the approach to fundamental concepts, such as substance, properties and transformation is extremely important for students to understand how simple everyday things work, according to Bachelard (1996) "substantialism is related to the monotonous explanation of the properties of substance. Thus, different qualities are attributed to substances, and these qualities are present within the substances themselves." Understanding these concepts not only

provides students with the necessary tools to interpret natural phenomena but also enables them to actively participate in society by understanding scientific issues related to industrial processes, the environment, and health. In this sense, the present research seeks to analyze the understanding of high school students in relation to the concepts of substance, properties and transformation, identifying knowledge gaps and proposing significant contributions to the improvement of the teaching of physics and chemistry.

This research aims to provide valuable information for educators, school curriculum and educational policies nowadays, according to Nunes and Adori (2010) "In today's society there is a high dose of information, which is not always properly treated. The school has become responsible for meeting this demand from students. In this sense, a large part of this task falls to the professional teacher who, in the development of technical and scientific knowledge, has to develop more and more skills in their students, which requires, in many cases, a broad and contextualized work". An in-depth understanding of certain topics in Physics and Chemistry can help to overcome obstacles that students may encounter, so abandoning such concepts will allow the design of more effective pedagogical strategies that promote meaningful and lasting learning.

This research not only highlights the intrinsic importance of the concepts of substance, properties and transformation in science teaching: according to Silva and Amaral (2013), "the idea of relational substance is based on the conception that in nature there are no isolated substances that do not interact with their environment". However, it seeks to offer tangible subsidies to improve the quality of teaching, promoting a more accessible, interesting, engaging and relevant scientific education for high school students.

2 GENERAL OBJECTIVE

The purpose of this article is to analyze the previous knowledge and degree of understanding of students in the first year of high school in relation to fundamental concepts of physics and chemistry, which were introduced in the ninth year of elementary school and deepened in the first year of high school. These concepts include substance, properties, and transformations. In addition, it seeks to present and discuss the results obtained in the processing of graphs from the answers of the applied questionnaires.

The specific objectives are:

- To analyze the students' level of understanding of the fundamental concepts of physics and chemistry addressed in the educational context.
- Investigate the conceptual bases that students bring with them as prior knowledge for the new learning cycle.
- Present and discuss in detail the results obtained from the processing of graphs generated from the answers of the applied questionnaires.

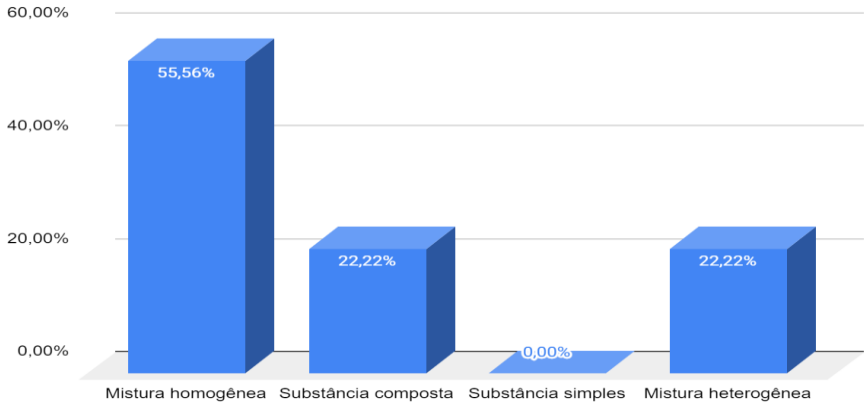
3 METHODOLOGY

This survey took place on August 25, 2023 (Friday), from 2 pm to 5 pm, with 120 students from the 1st year of high school who were present. Through an extension applied in an Orlando Venâncio dos Santos Integral Citizen school, in the municipality of Cuité-PB. With the main objective of investigating the students' conception of physicochemical phenomena about substances, properties and transformations. For this, we conducted an interview with each student individually, in which they answered a questionnaire with 9 (nine) objective multiple-choice questions, and the tenth question had four open questions. The results were analyzed quantitatively.

4 DEVELOPMENT

In this study, it was observed that a considerable portion of students face significant challenges when interpreting the fundamental concepts of physics and chemistry (Graph 1). This difficulty can be attributed to a number of factors, ranging from the intrinsic complexity of these concepts to the pedagogical approaches employed in classrooms. Inadequate understanding of these scientific foundations not only compromises students' academic performance, but also undermines their ability to apply this knowledge in practical contexts, which are essential for integral formation and conscious citizenship.

GRAPH 1. CONCEPTIONS ABOUT THE NATURE OF THE COMPOSITION OF GASOLINE.



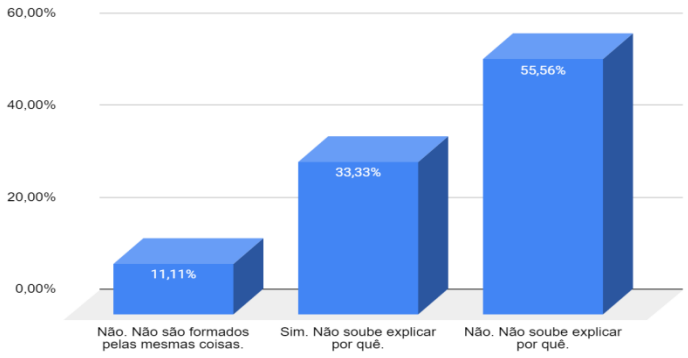
Source: Survey data, 2023.

Graph 1 shows the distribution of responses to the question about the nature of gasoline composition. According to Lisboa (2010) "*when one substance is added to another, they cease to be pure and become the substances of a new system called mixture*". Gasoline is a homogeneous mixture of hydrocarbons where octane has a higher percentage in the composition. According to Graph 1, approximately 56% of the interviewees marked the correct alternative *(homogeneous mixture)* and 44% marked other alternatives. The alternative *(compound substance)* obtained approximately 22% of the answers, which may indicate that

the students, even if they have the statement in the statement that gasoline is formed by hydrocarbons, common sense can affirm, by the physical aspects, that gasoline does not have other components, being a pure substance. 22% of respondents answered that gasoline is a *(heterogeneous mixture),* This exposes a necessary recapitulation of this concept.

Gasoline is a fuel with a complex and varied composition, which includes hundreds of hydrocarbons of different types and structures. These hydrocarbons have, in general, 4 to 12 carbon atoms per molecule (REBOUÇAS, 2003). According to Marshall, a fuel composed only of isooctane has an octane number of 100 (100 NO), and a heptane compound of 0 (0 NO). As shown in Graph 2 of the research that was carried out on whether an octane molecule has the same properties as a gasoline sample, among the interviewees 55.56% stated that the octane molecule did not have the same properties as gasoline, but could not explain why, 33.33% stated that yes, that the octane molecule has the same properties as gasoline, But they could not explain why, the other 11.11% agree that they are not, because they are not formed by the same molecules.

GRAPH 2. CONCEPTIONS ABOUT WHETHER AN OCTANE MOLECULE HAS THE SAME PROPERTIES AS A GASOLINE SAMPLE.



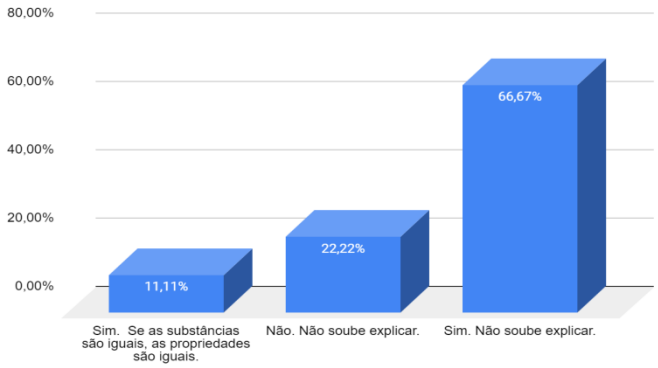
Source: Survey data, 2023.

Physics and chemistry, as scientific disciplines, often involve abstract concepts and complex processes, making them challenging for many students. The transition from a superficial understanding to a deeper understanding requires not only the assimilation of information, but also the ability to relate these concepts to real-world phenomena. The teaching of these disciplines should, therefore, seek strategies that make the concepts more accessible, using practical approaches, experiments and everyday applications.

Iron is a transition metal located in group 8 of the Periodic Table, a chemical element that features the symbol Fe, atomic number 26, and atomic mass 55.847u. Iron is found in ores mainly in the form of oxides and hydroxides, being the most used metal in the world and the most exported from Brazil, the main use of iron is for the production of steel, used, for example, in civil construction, manufacture of cars and household appliances. According to Atkins and Jones (2006). *"All matter is made up of various*

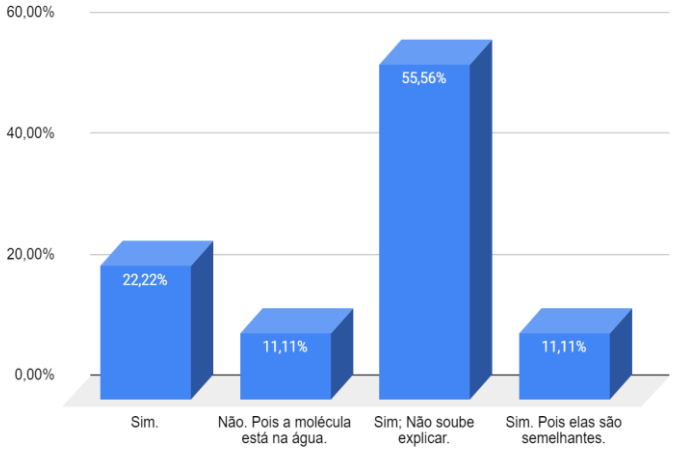
combinations of simple forms of matter, called chemical elements. An element is a substance made up of a single type of atom." Graph 3 represents the number of respondents who answered the following question: "Are properties such as electrical and thermal conductivity, density and melting point, characteristics of an iron sample maintained in an iron atom? Why?" About 66.67% answered yes, but could not explain why, 22.22% answered no, but also without explanation, and the remaining 11.11% answered yes, that if the substances are the same, the properties are the same.

Graph 3. Conceptions about the properties of a metal.



Source: Survey data, 2023.

Graph 4. Conceptions about the properties of a molecule.



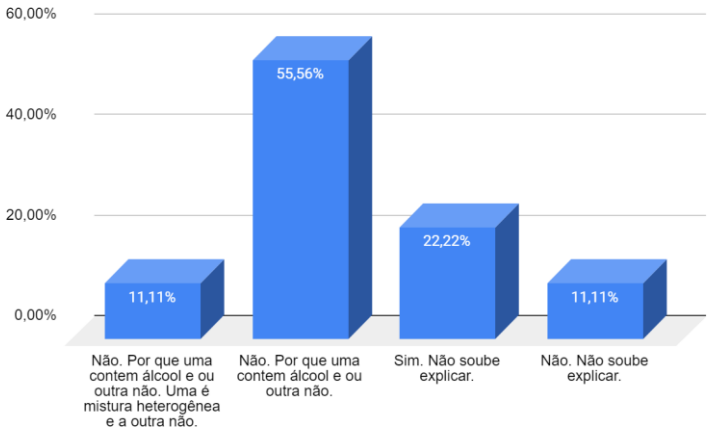
Source: Survey data, 2023.

The water molecule (H2O) is formed by the grouping of two hydrogen atoms and one oxygen atom. The heat capacity of water is very high (1 cal/ºC), when compared to most known substances (< 1 cal/ºC), water is able to acquire or lose much more heat than other common substances, when subjected to the same temperature. Physical properties are those that do not change the identity of a substance. Chemical properties are those that change the identity of a substance. Extensive properties depend on the mass of the sample, unlike intensive properties. The accuracy of a measurement indicates how close they are to each other, while

the accuracy of a measurement indicates how close the mean of the measurements is to the actual value (ATKINS; JONES, 2006). In Graph 4, 55.56% of the interviewees answered Yes, but could not explain, 22.22% claimed only Yes, and another 11.11% said No. Because the molecule is in the water. And the remaining 11.11% agreed yes. For they are similar.

In question 5 (Graph 5), in which the question was "It is known that the gasoline we consume as motor fuel has, according to Brazilian legislation, a certain amount of alcohol. Do two samples of gasoline, one with and one without alcohol, have the same chemical properties? Why?", about 66.67% answered correctly, because if one sample of gasoline has alcohol and the other does not, they will have different substances and properties. 11.11% of the students still answered correctly, so they did not explain the reason for their answer. And 22.22% answered wrong. According to Fonseca (2013) *"Any material can be considered a substance when it has all its properties defined, determined and practically invariable under the same conditions of temperature and pressure."*

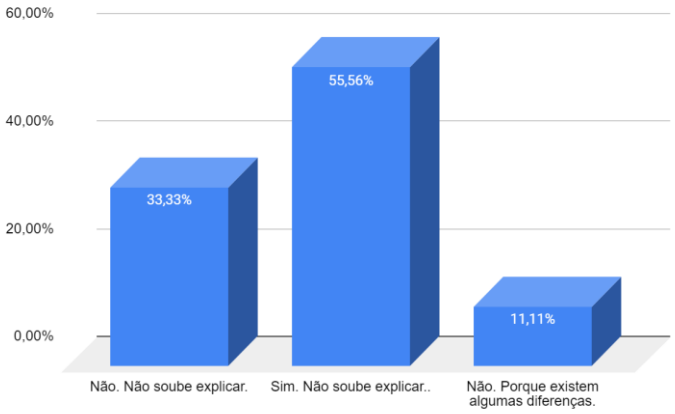
Graph 5. Conceptions about the properties of gasoline.



Source: Survey data, 2023.

The gasolines sold today are formulated by mixtures of these currents in varying proportions to meet the specifications of the 19 regulatory bodies, which in the case of Brazil is the National Agency of Petroleum, Natural Gas and Biofuels (ANP, 2001). In question 6 (Graph 6), it was asked whether the molecules and the substance of the same material have the same chemical and physical properties. Theoretically, none of the students got it right, because the correct answer would be chemistry. 55.56% of the students answered yes, but did not know how to explain, and 44.44% of the students answered no, and also did not know how to explain.

Graph 6. Conceptions about the properties of molecules and substances.

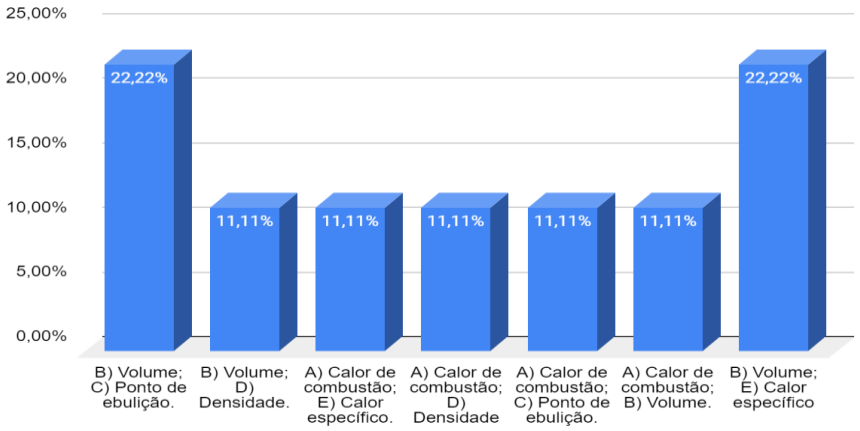


Source: Survey data, 2023.

There is a clear difficulty in understanding these phenomena. In addition, difficulties can be exacerbated by teaching methodologies that are outdated or disconnected from students' needs and interests. The lack of educational resources, equipped laboratories, and the practical application of acquired knowledge can contribute to a gap between academic content and its real-life application. Thus, it is crucial to rethink pedagogical strategies, integrating innovative methods that stimulate curiosity, active participation, and the practical application of scientific concepts.

In question 7, the question was which of the properties mentioned below depend on the amount of mass of the same alcohol sample. The students were very divided regarding the alternatives, that there were two correct answers. According to Graph 7, only 11.11% answered the question correctly and 88.89% answered one correct alternative and the other wrong. According to Fonseca (2013), boiling occurs at a certain temperature (which varies with the local atmospheric pressure) and is characteristic of certain species of matter.

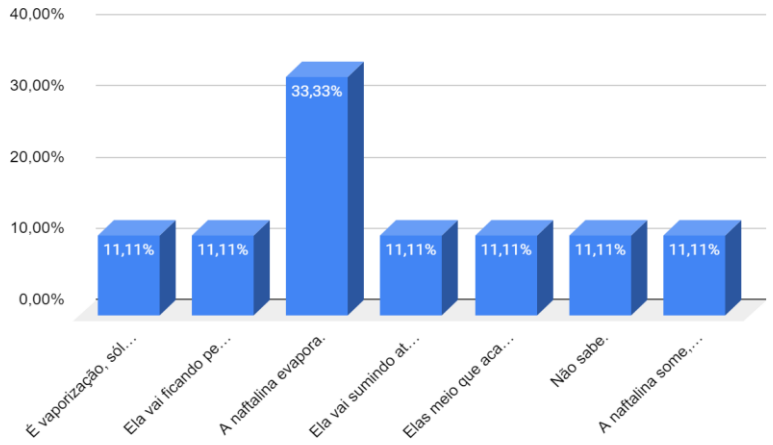
Graph 7. Conceptions about physical properties.



Source: Survey data, 2023.

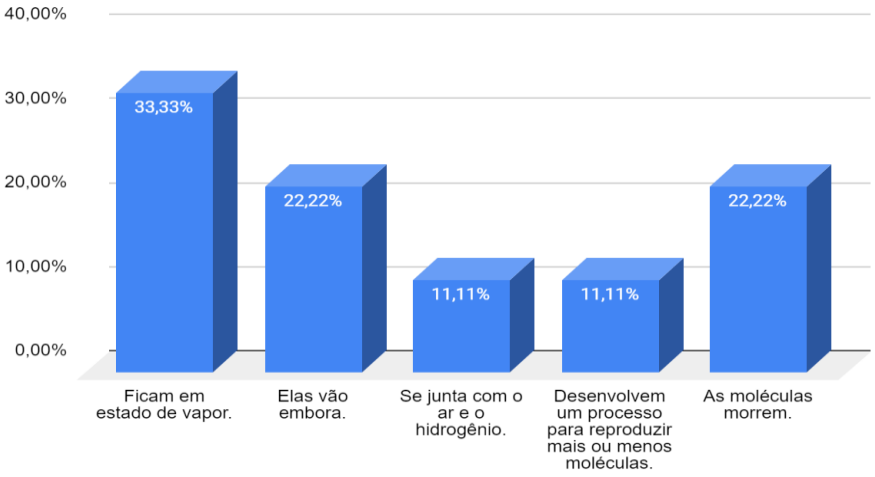
Graph 8 shows the distribution of responses to the question, *'How do you explain the decrease in the size of the mothballs over time?'*. According to Fonseca (2013) *"The transformation of a material that goes from a solid to a gaseous state is called sublimation [...], when slightly heated the mothballs undergo sublimation"*. To analyze the answers, we classified them into two categories: partially correct and incorrect. According to graph 1, 11.11% of the respondents' answers are in the partially correct category, an example of the answers provided was *"It is vaporization, solid to gaseous" (E1).* In the incorrect category, approximately 33% of respondents stated that mothballs go through the vaporization process, *11.11% said that* mothballs melt because of heat, and another 44.89% explained it by other concepts. Graph 9 shows the breakdown of the answers to the question *"During the decrease in mothballs, what happens to the naphthalene molecules?"*.

Graph 8. Comparisons on the physical phenomenon of sublimation.



Source: Survey data, 2023.

Graph 9. Conceptions about the physical phenomenon of sublimation.



Source: Survey data, 2023.

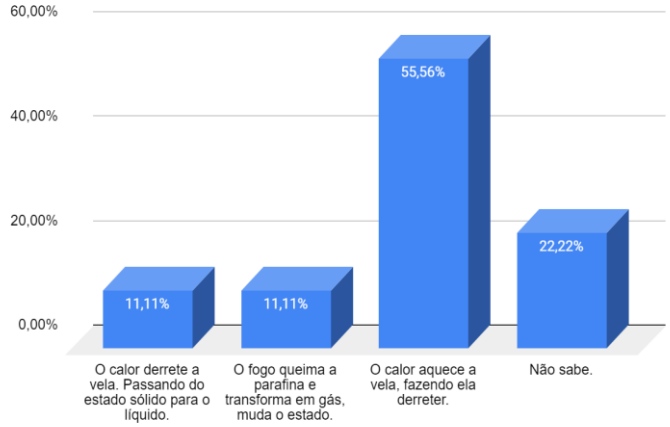
About the Law of Conservation of Masses and the molecular view in the process of sublimation of mothballs, we can state:

> Lavoisier also correctly explained that the apparent loss of mass that accompanies the loss of materials, such as carbon, graphite, and paper, occurs because the combustion products are gaseous and leave the system; However, if the masses of all the substances involved in a chemical reaction are considered, there is no loss or gain of mass in the final balance. (FONSECA, 2013, p. 91)

According to Fonseca (2013) *"Joseph Priestley [...], assumed that the new gas was present in the atmosphere, which, therefore, must be composed of a mixture of gases"*. According to Graph 1, approximately 33% of the interviewees answered correctly and another 67% answered incorrectly. According to Graph 9, in the correct category, 33.33% of respondents said that naphthalene molecules "*become vapor-like."* In the incorrect category, for 44.44% of the interviewees, the molecules *die* or *go away*. Another 22.22% of the respondents' answers are the following examples of answers that were provided, example 1: "*They develop a process to reproduce more or fewer molecules" and* , example 2: *"Joins with air and hydrogen"*.

Graph 10 shows the distribution of responses to the question *"How do you explain the candlestick phenomenon?"*. According to Giordan (1999) *"It is a consensus of chemistry professors and researchers that experimental activities help in the consolidation of knowledge, in addition to helping in the cognitive development of the student"*. To analyze the answers to this question, we classified them into two classes: *they did not know how to answer, partially correct;* and the *partially correct objective* subclass. According to Graph 10, in the category of partially answered, 77.78% and another 22.22% did not answer. In the partially correct category, 11.11% explained *"Heat melts the candle. Moving from a solid to a liquid state."* For 11.11%, *"Fire burns the paraffin and transforms it into gas, it changes the state"*. In the subclass category, approximately 55% answered what happens to the candle, without further explanation of the physical process. And another 22.22% did not know how to answer.

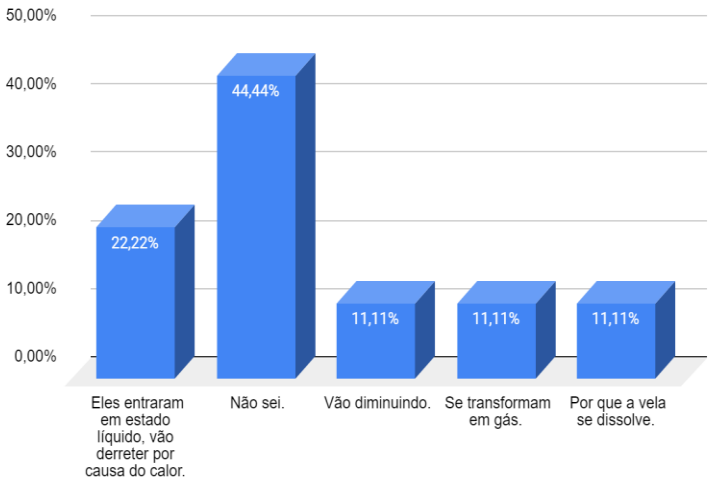
Graph 10. Conceptions about the phenomenon of candle combustion.



Source: Survey data, 2023.

Graph 11 shows the breakdown of the answers to the question: *"What happens to the paraffin molecules?"*. According to Fonseca (2013) *"The melting point is characterized by the change of the material from the solid state to the liquid state and the boiling point is characterized by the change of the material from the liquid state to the vapor state."* According to Graph 11, we categorized the answers as: *partially correct*, *incorrect*, and *did not know how to answer*. Approximately 33% of the respondents' answers are in the partially correct category, as they did not fully respond to the phenomenon. In the *incorrect* category are about 23% of the answers. In the category *they did not know how to answer is approximately 44% of the interviewees, who did not know how to answer what happens to paraffin molecules.*

Graph 11. Conceptions about paraffin in candle combustion.

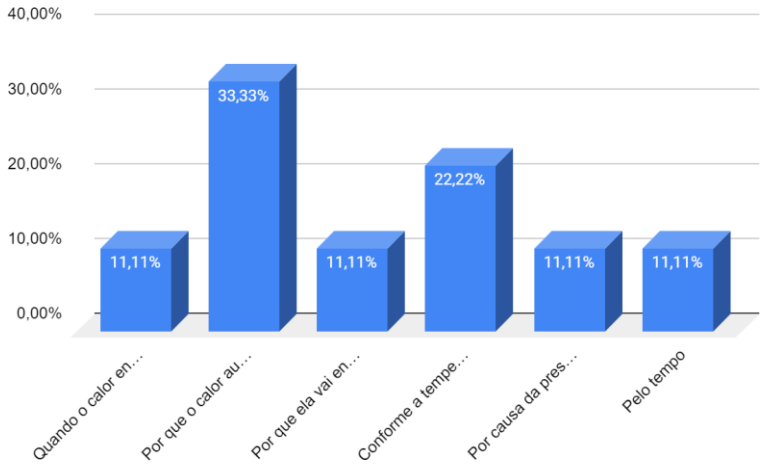


Source: Survey data, 2023.

Graph 12 shows the distribution of answers to the following question related to spark plug combustion, *"Why does mass decrease occur?"*. According to graph 12, we see a disparity between the

answers, each with its own particularity, so in this case, we will analyze by bar, but analyzing under the categories: correct, *partially correct and incorrect.* In the *partially correct category*, approximately 33% of respondents' responses were: *"Why does the heat increase. It's solid, it's going to be liquid."* The 22.22% answered objectively, without presenting the physical states. In the *correct* category, there are the first 11.11% who answered more completely, providing the following answers: *"When heat comes into contact with paraffin, the temperature will cause it to melt. Going into a gaseous state."* The remaining answers, totaling 33.33%, correspond to the incorrect category.

Graph 12. Conceptions about the decrease of mass in the combustion of the candle.



Source: Survey data, 2023.

Graph 13 shows the distribution of responses to the following question related to candle combustion: *"Where does candle heat come from?" In this category there is no interaction between the combustible substance and oxygen/air. Oxygen/air may or may not be recognized as necessary for combustion and there being necessary to keep the flame alive."* (WATSON, PRIETO and DILON, 1997). To analyze the answers, we will divide them into categories, namely: *correct and partially correct.* In the *partially correct category, 44.44%* of the respondents' answers were: *"From the wick inside the candle"*. And 11.11% of respondents answered that the heat comes *"from the steam of the candle"*. In the *correct category, 22.22% answered that "The heat of the flame comes from the paraffin itself"*. In the *incorrect category,* 22.22% of respondents answered that heat comes *"from oxygen"*.

Finally, addressing these difficulties requires close collaboration between educators, researchers, and education policymakers. The implementation of differentiated pedagogical approaches, the promotion of interactive learning environments, and the constant updating of the curriculum are fundamental steps to overcome the challenges observed in this study. By doing so, we can not only improve understanding of the

basics of physics and chemistry, but also inspire a generation of students to become critical thinkers and active participants in the construction of scientific knowledge.

5 FINAL THOUGHTS

Based on the results presented in the graphs, it is evident that there are significant gaps in students' understanding of fundamental chemistry concepts. Issues related to mixtures, substances, properties, molecules and physical processes demonstrate the need to review and deepen these issues.

The data suggest that students face particular challenges in understanding the distinction between chemical and physical processes, properties of substances, and the molecular nature of matter. The importance of experimental activities to consolidate concepts is also highlighted, especially in view of the significant percentage of inadequate responses in the "did not know how to answer" category.

Therefore, a more practical pedagogical approach is recommended, in a more dynamic and contextualized way, focused on experimental activities and concrete examples to strengthen students' understanding. Additionally, it is crucial to emphasize the importance of the conceptual basis in fostering a more solid and applied understanding of physical and chemical principles.

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