Article

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The meanings future Chemistry teachers give to chemical concepts in teaching: a look from the Cultural-Historical School's perspective

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Abstract

This paper presents the results of a research whose general objective was to characterize the meanings that future Chemistry teachers attribute to concepts in the context of learning in basic education, based on the logical-cognitive framework of the Cultural-Historical School of Psychology. 46 undergraduate students participated in the research. Data collection was conducted using a pedagogical test. The information obtained was analyzed according to Lexicon Analysis and the analysis based on the protocol by Núñez and Silva (2020). The results showed that, in general, the undergraduates confuse the chemical concept with its definition, referring to it as *something* or *one thing* and not as an image of a class determined by its essential characteristics and relations. Furthermore, they do not relate them to the processes of dialectical logical thinking. This situation highlights the importance of initial teacher formation contemplate various possibilities of this epistemological and professional teaching knowledge.

Keywords: Meanings. Chemical Concepts. Initial formation. Chemical Thinking.

Os sentidos de futuros professores de Química sobre conceitos químicos no ensino: um olhar sob o enfoque da Escola Histórico-Cultural

Resumo

Neste trabalho, apresentam-se os resultados de uma pesquisa cujo objetivo geral foi caracterizar os sentidos que futuros professores de Química atribuem aos conceitos no contexto da aprendizagem da educação básica, tomando como pressuposto o referencial lógico-cognoscitivo da escola Histórico-Cultural da Psicologia. Participaram da pesquisa 46 estudantes de licenciatura. Para a coleta de dados, utilizou-se uma prova pedagógica. As informações obtidas foram tratadas segundo a Análise do Léxico e a análise baseada no protocolo de Núñez e Silva (2020). Os resultados evidenciaram que os licenciandos, no geral, confundem o conceito químico com sua definição, referem-se a ele como *algo ou alguma coisa* e não como uma imagem de uma classe determinada pelas características e relações essenciais dela. Por sua vez, não os relacionam aos processos do pensamento lógico dialético. Essa situação evidencia a importância de a formação inicial de professores contemplar diversas possibilidades desse conhecimento epistemológico e profissional docente.

Palavras-chave: Sentidos. Conceitos Químicos. Formação inicial. Pensamento Químico.

Los sentidos de los futuros profesores de Química sobre conceptos químicos en la enseñanza: una mirada desde la perspectiva de la Escuela Histórico-Cultural

Resumen

En este trabajo presentamos los resultados de una investigación cuyo objetivo general fue caracterizar los sentidos que los futuros docentes de Química atribuyen a conceptos en el contexto del aprendizaje de la educación básica, tomando como presupuesto el marco lógico-cognitivo de la Escuela Histórico-Cultural de Psicología. 46 estudiantes de pregrado participaron en la investigación. Para la recolección de datos se utilizó una prueba pedagógica. La información obtenida fue tratada según Análisis de Léxico y el análisis basado en el protocolo de Núñez y Silva (2020). Los resultados mostraron que los estudiantes de pregrado, en general, confunden el concepto químico con su definición, refiriéndose a él *como algo* o *alguna cosa* y no como una imagen de una clase determinada por sus características y relaciones esenciales. A su vez, no los relacionan con los procesos del pensamiento lógico dialéctico. Esta situación resalta la importancia de la formación inicial docente contemplando diferentes posibilidades de este conocimiento epistemológico y profesional docente.

Palabras clave: Sentidos. Conceptos químicos. Formación inicial. Pensamiento químico.

Introduction

Studies about the thinking of Chemistry teachers as a type of professional thinking for teaching this subject in basic education have been conducted by several authors, from different theoretical perspectives. Among these studies, we highlight two perspectives: that of cognitive sciences (Talanquer, 2019; Taber, 2019) and that of what we call the Cultural-Historical School of Psychology (EHCP, in portuguese), which includes the research of Gilmanshina (2005a), Volkova (2018), Núñez and Bandeira (2024) and Núñez and Ramalho (2020).

From the perspective of EHCP, based on contributions to the thinking of Vygotski (2009), Leontiev (2021), Davidov (1998), Galperin (2023), the chemical thinking of the Chemistry teacher, along with pedagogical thinking and developmental methodological thinking, configure teacher's professional thinking. The relevance of studies on this type of teaching thinking is justified by the importance attributed to it in the teacher's professional practice as well as in their learning, training and professional development processes (Núñez; Ramalho, 2020). According to Ilienkov (2007), whoever wants to teach how to think must learn and know how to think too. For the author, one cannot teach others to do what they do not know. If schools aim to teach how to think, teachers must, above all, learn to think, which implies developing their professional thinking.

For Gilmanshina (2008), the main characteristics of the professional thinking of a Chemistry teacher, as well as the criteria for its development, are: mastery of the subject of pedagogical activity; logical thinking, implemented during scientific explanation in this subject; and mastery of the research method applied to solving problems in the subject they teach, resolving specific dialectical logical problems of pedagogical training. Thus, logical thinking (formal and dialectical) is an essential aspect in the training of Chemistry teachers from this perspective.

This thought implies thinking characterized by the possibilities offered by scientific concepts, integrated into theoretical systems, with logical consistency and validity, recognizing the limits of application of the concepts as human historical and social constructions. In this way, the relevance of chemical concepts in the development of logical-verbal thinking (formal and dialectical) is evidenced, for the training of Chemistry teachers.

The teaching of chemical concepts demands from the teacher the mastery of different perspectives and foundations about what they are and how they are taught. Núñez and Bandeira (2024) have drawn attention to the importance of Chemistry teachers knowing that the formation of concepts is a different process from knowing information, which requires less intellectual effort from students. In turn, Taber (2019) emphasizes that the teacher needs to know the nature of scientific concepts, their place in the structure of science and chemical thinking, as well as having professional knowledge that can support student learning. Knowledge about what a chemical concept is helps teachers of this discipline to understand, under logic (formal and dialectical), forms of thinking with chemical concepts, such as judgments, reasoning, and theories.

All the previous discussion leads us to affirm how important it is for teachers to have a clear stance on what a chemical concept is for the formation and development of logical dialectical thinking in Chemistry classes. This type of thinking contributes to scientific reasoning as well as to its teaching.

Given the reflections explained based on EHCP, the following research problem was defined: What meanings are attributed by students of a Chemistry teaching degree to chemical concepts as forms of logical thinking, in the context of teaching this subject? What representations do the undergraduates have about what a scientific concept is, in the context of Chemistry teaching? What knowledge, in turn, are expressed by them when defining a chemical concept and presenting the justification for its learning by students, in Chemistry classes?

Chemical concepts from the perspective of the Cultural-Historical School of Psychology

Under the EHCP approach, initiated by L. S. Vigotsky as a theoretical and interpretative framework, chemical concepts and their formation in the school context have a logical-cognitive foundation based on the philosophy of dialectical materialism and are linked to logical-verbal thinking, as a cognitive activity of personality.

In Vigotsky's (2009) understanding, concepts are the results of a superior mental activity that is realized in connection with each individual's history, with generalized meanings considered as the result of internalization/externalization processes within the context of social activity and communication. For Galperin (2023), the concept is the form of mental activity through which the idealized object and the system of its essential relations are actively reproduced, which, in their unity, reflect the universality or the essence of the object's movement in its development. The concept acts simultaneously as a form of reflection of the object in the subject's consciousness and as a means of mental image, of its structuring, that is, linked to a special mental action. Ilienkov (1977) understands that the concept is the main product, in thought, of the reflection of the general and substantial qualities of objects and phenomena of reality. Thus, concepts are interconnected in complex dialectical systems as well as being formers of new theoretical configurations, in which particular concepts are related to others with greater epistemic power and are integrated into them.

For Núñez, Pereira and Barros (2024), scientific concepts correspond to a generalized image that subjectively and dialectically reflect in human consciousness a multiplicity of objects, phenomena, and processes of the same class, based on their essential characteristics and connections, result of scientific activity. Scientific knowledge is organized and systematized from systems of concepts, as a dialectical systemic totality. According to the authors, in scientific concepts, the essential contradiction lies in the unity of the objective with the subjective. Thus, the concept is subjective, as a mental abstraction elaborated by subjects, but also objective, as it relates to human social activity, directly or indirectly, that is, through its content.

Davidov (1998) emphasizes that science strives to move from the description of phenomena to the discovery of their essence, as their internal connection, with the essence having a different content from the phenomena and the sensorial-perceptual properties resulting from the way individuals perceive objects. The chemical concept provides chemical thinking, which, according to the ideas of Davidov (1998), is a theoretical thinking.

This concept, unlike a representation, in dialectical logic, must reveal not only the essential links between objects, but also their movement as a result of dialectical contradictions that influence their historicity. These concepts do not refer to concrete objects, but are theoretical formulations that express the essential characteristics and relationships between classes of objects, in a dialectical movement of essence-phenomenon. Thus, conceptualization (definition) is a process of abstraction-generalization typical of scientific activity, through verbal language.

In language, concepts are expressed by words ("atom", "molecule", "entropy") or nominal expressions ("activation energy", "functional analytical groups"). The concept reflects only the essential characteristics of objects. Each essential characteristic, separately from the others, is necessary, and all together are sufficient to distinguish a particular object from all others.

According to dialectical logic, it is possible to identify, in a concept, its content and its extension (Talízina, 2023). The content is determined by the number of necessary and sufficient properties that are included in the definition of the concept. The extension refers to the number of objects, processes or phenomena that fall within the determined class to which the concept refers.

From a structural point of view, chemical concepts can present the following logical structures: conjunctive, in which the essential characteristics are joined by the conjunction "and"; disjunctive, in which they are related by the conjunction "or"; disjunctive-conjunctive, in which they are sometimes joined by the conjunction "or" and sometimes by "and". These structural forms of concepts are important for understanding the nature of chemicals. The concepts of Chemistry, in the form of chemical thinking, are psychological tools necessary for reasoning and judgment processes in this area, which leads to a certain range of conceptual relationships and new knowledge.

Typologies of chemical concepts in the context of school teaching

Chemical concepts, considered as concepts of the sciences, can be classified according to different criteria, which helps to deepen their nature as a product of scientific practice in Chemistry. Among the possible classifications, related to EHCP and its logical-dialectic foundations, those established by Vygotski (2009), Davidov (1998) and Hedesa (2014) can be discussed.

Vygotski (2009) classifies concepts into scientific and everyday (spontaneous), based on the criteria of their formation. The first are the concepts of scientific culture, which are the object of learning at school, while the second are formed in everyday life, based on experience at the sensorial-perceptual level. Thus, the chemical concepts studied at school, according to Vygotski (2009), belong to scientific concepts.

Davidov (1998) categorizes concepts into empirical (everyday or empirical scientific) and theoretical (scientific). The first are based on formal logic, and the second, on dialectical logic, which, in turn, is related to the type of generalization or mental actions involved in their formation processes. For him, theoretical concepts have as their specific content the objective relationship between the universal and the singular. In these concepts, the interrelationships in a whole of isolated objects are discovered, within the system of their formation. They are the result of theoretical thinking, typical of scientific activity. On the other hand, empirical concepts are formed by the mechanisms of empirical generalization, through the process of comparing objects, supported by the observation of reality, which is realized in relation to examples and illustrations. They reflect the phenomenological aspects of the class they represent.

In Chemistry, concepts have also been classified in other ways within the scope of the EHCP. Hedesa (2014) typifies chemical concepts as primary and secondary. The primary or fundamental concepts, which form the basis for developing the conceptual system of Chemistry and from which the secondary concepts derive, are: substance, chemical reaction, chemical element, chemical structure and quantity of substances.

Hedesa (2014) refers to another typology of chemical concepts of importance for teaching, which include those related to: a) chemical objects (sulfur); b) chemical events or processes (combustion); c) qualities of chemical objects and processes (conductivity); d) metaconcepts (chemical law), to which other concepts are related.

Research methodology

The study is qualitative and exploratory in nature, as it seeks to characterize a little-discussed subject in the context of initial teacher training in Chemistry, according to Núñez and Bandeira (2024). The research was conducted with 46 students in the fourth year of a Chemistry teaching degree course, in the subject Supervised Internship for the Teaching of Chemistry IV, at a public university. The students were aged between 18 and 46, with an average of 25 years (63.0%), 42.6% of whom were female and 57.4% male. All of them had taken the theoretical and pedagogical subjects of the initial training. Of them, 25.6% had up to 3 years of experience in teaching activities. The others had no experience in this regard. For the purpose of result analysis, they were identified numerically, as undergraduate 1 to undergraduate 46.

For data collection, a Pedagogical Test was used, applied within the context of the subject. The pedagogical test, according to Núñez (2018), allows the revelation of representations and levels of knowledge related to the meanings that subjects attribute to a certain study content. The test was developed according to the research objectives and validated by another researcher, in order to guarantee the credibility of the study. The test plan is explained in Table 1.

Table 1 – Pedagogical Test Plan

<table>
<tr><th>Objective</th><th>Questions</th></tr>
<tr><td>Characterize undergraduate students' representations of what a scientific concept is in the teaching of Chemistry.</td><td rowspan="2">Regarding the teaching of Chemistry, in the school context:
a) What is a scientific concept?
b) Define a Chemistry concept taught in school.
c) When can it be said that the student has mastered a Chemistry concept?
d) In the Chemistry course, in any or in some subject(s), was it discussed what chemical concepts are and their importance in students' scientific education?
Yes______No _______
Justify your answer if yes.</td></tr>
<tr><td>Characterize undergraduate students' knowledge of what a scientific concept is in Chemistry teaching.</td></tr>
</table>

Source: The authors (2023)

The test was administered in the classroom with a total of 3 hours available. Some of the students' questions were presented and clarified after they had signed the confidentiality agreement. All students expressed interest in answering the questions on the pedagogical test.

The responses to the first question of the test – What is a scientific concept? – were analyzed using Lexicon Analysis and Similarity Analysis (Camargo;

Justo, 2013). These analyses were conducted with the help of the IRAMUTEQ software – in French "*Interface de R pour les Analyses Miltidimensionelles de Textes et de Questiónnaires*" – (Ratinaud; Dejean, 2008), which allowed the characterization of undergraduate students' representations of what scientific concepts are.

The IRAMUTEQ software was used to create a word cloud, where the words were grouped and graphically organized according to their frequency in the answers to the first question (What is a chemical concept?). Since the font size is proportional to the frequency of words in the analyzed corpus, this lexical analysis is graphically interesting, despite being simpler. In turn, the Similitude Analysis allowed the elaboration of the similitude tree, by identifying the combinations between the words and the result, indicating the connections between them as well as highlighting the most representative clusters in the set of responses to the question, as discussed by Camargo and Justo (2013), which made it possible to complement the information represented in the word cloud and, from this, highlight the representations under study by the undergraduates.

Regarding the analysis of the question "Define a Chemistry concept", an analysis was conducted following the protocol used by Núñez and Silva (2020), establishing theoretical categories to evaluate the knowledge of undergraduates. Based on the content of the categories, the criteria of adequacy, clarity and distinction were used. A definition is adequate when it allows the mental representation of the class in which all its essential characteristics are present. It is clear when it enables the identification of any object belonging to the class. It is distinct when it allows for a clear differentiation of the class's attributes. According to possible relations of the aforementioned categories, the responses were classified as: a) correct (when they satisfactorily comply with the three criteria), b) partially correct (if two criteria are adequate and one is inadequate), c) incorrect (when at least two criteria are incorrect) and d) does not define the concept. In turn, the concepts were classified according to the typologies discussed by Hedesa (2014).

For the analysis of the responses to the question "When can it be said that the student has mastered the scientific concept in Chemistry classes", an analysis was also conducted based on a type of protocol developed by Núñez and Silva (2020). Empirical categories were developed by determining their frequencies, which allowed obtaining data relating to knowledge to be integrated with the analyzes of the previous question.

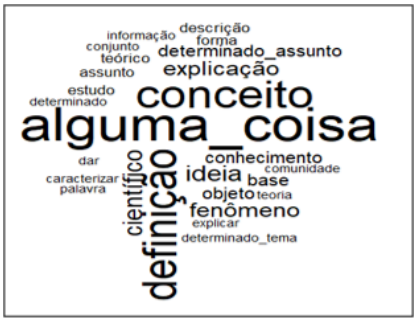
The meanings that the undergraduates attributed to what is a scientific concept, in the context of teaching Chemistry, in the basic education curriculum, were inferred from the triangulation of data from the lexical and content analysis of the three items (a, b and c) of the pedagogical test. This procedure, as explained by Núñez (2018), provides greater credibility to the analysis of the results concerning the responses given to the study questions.

Results and discussion

The first question of the pedagogical test aimed to characterize undergraduate students' representations of what a scientific concept is, in the context of teaching Chemistry, in basic education. As explained in the methodology, the responses to this question were analyzed according to Lexicon Analysis, including the creation of a Word Cloud and the Maximum Similitude Tree. An initial lexicon analysis revealed a significant presence of the words "something" and "one thing."

This word cloud for the response to the question allowed for the graphical grouping and organization of words based on their frequency. As shown in Figure 1, the words *concept*, *definition* and *scientific* as well as the nominal expression *something*, which is the most prominent, are those that appear most frequently in the lexicon.

Figure 1 – Word Cloud for the responses to the question "What is a scientific concept?"



Source: Developed by the authors using IRAMUTEQ (2023)

It is important to highlight that, in the term "*something*", both *something* and *one thing* were included, since, in the responses, it was found that they were used with the same semantic content. Besides these dominant lexicon items, there are others that appear less frequently, such as *explain*, *theme* and the nominal expression *certain subject*, among others. It is also worth noting the absence of words such as *image*, *mental*, *thought*, *generalization*, *logic*, *dialectic*, *reasoning*, *judgment*, and others that are part of the lexicon of the theoretical content of what a scientific concept is from the perspective of EHCP, which indicates a certain distance from the lexicon of the undergraduates when answering the question. The term "Something" may signal that there is no proper use of chemical language when answering this pedagogical test question, considering that terms specific to this scientific language do not appear.

Next, to analyze the structure of representations in the undergraduates' responses, the Similitude Analysis was conducted. Through the construction of these graphical representations, it is possible to highlight not only the most frequent terms in a text but also the relations between the terms, indicating the most important connections made by the undergraduates, which to some extent express the structure of the representations of the object under study, according to Camargo and Justo (2013). In Figure 2, the Similitude Tree, constructed with the corpus originating from the set of responses to the aforementioned question, is presented.

Figure 2 – Similitude Tree for the responses to the question "What is a scientific concept?"

Source: The authors (2023)

In the tree, three relevant cores of relationships between concepts can be seen, formed by the nominal expression *something* (which includes the word *thing*), and the terms *definition* and *concept*, which constitute the elements from which the other words are organized and related in what is assumed to be the structure of the most prevalent representations in the undergraduates' responses. In Table 2, the highest co-occurrence values of the three word cores can be observed.

Table 2 – Pairs of words and nominal expression with the highest co-occurrences

Pairs	**Co-occurrence value**
definition – something	19
concept – definition	5
definition and scientific	4

Source: The authors (2023)

Out of the 46 responses, 19 used the word *something* or the nominal expression *one thing* in these types of relations. The texts below provide examples of such responses:

> *Something* that explains, underpins, a phenomenon (undergraduate 21, 2023).
>
> [...]
>
> It consists of a description of *something* developed by a community that conducts research/studies on such a topic/subject (undergraduate 23, 2023).
>
> [...]
>
> It is when there is an idea through *one thing*, that is, when one has an opinion about *one thing* (undergraduate 37, 2023).
>
> [...]
>
> Concept is a set of words designed to characterize and/or give meaning to *something* (undergraduate 40, 2023).

When referring to scientific concepts as "something" or "one thing", the undergraduates do not relate them to what a concept is, in the sense of dialectical logic, as an image of reality labeled by specific signs, not an object, phenomenon or process, but of a set or class that shares essential properties and relationships and are the result, among others, of processes of theoretical generalization of the scientific activity of chemists (Núñez; Pereira; Barros, 2024). This absence relates to a particular epistemological understanding of the undergraduates about the nature of scientific knowledge and its production. In general, it is considered that the concepts constructed by science correspond to a "special" class of abstract concepts, due to their general nature and their impossibility of direct perception, as many of them correspond to theoretical entities.

The idea of the concept as something, as a thing, is supported by teachers, as argued by Taber (2019). For him, a concept is an idea through which an object is represented, as an immediate sign of it, being a direct reference to the real object, in line with empirical concepts, as understood by Davidov (1998). Thus, there is a reference to the thing, to something in a representative and substitutive manner, with the object existing for the intellect as well as being thought about. In the author's understanding, the concept represents and substitutes the thing at the level of intelligence. In this case, according to Taber (2019), it is an empirical concept.

According to the logical-cognitive foundations of EHCP, a characteristic of a concept is being a mental image of a class of objects as a form of logical thought (Talízina, 2023). In the case of scientific concepts taught in schools, they are the result of theoretical generalization processes (Davidov, 1998), aimed at expressing, according to dialectical logic, the essence of the class, and not just the external common, typical of empirical generalization. Nevertheless, this analysis requires a deeper understanding of what "something" means to the undergraduates.

As observed in the responses, there is no establishment of relations between the word *something* or the nominal expression *one thing* and the words *representation*, *thought*, *essence*, *generalization and dialectical logic*. The fact that undergraduates do not establish a relation with scientific concepts, specifically with the nominal expression *mental representation*, may signal a certain naive realism, according to Gilmanshina (2008), regarding the undergraduates' understanding of what chemical concepts are. This may manifest in the activities they develop in Chemistry classes, with negative consequences for the scientific education of students.

In EHCP, this type of representation by undergraduates may interfere with the teaching of scientific concepts in Chemistry at school, as the concept is singularized when it is reduced to something or one thing or to a certain "substantialized" form, something concrete. This understanding by undergraduates may be influenced by an ontological view that leads them to confuse the concept (as an image) with an object of the class it represents. Thus, the concept, not being a concrete sensory image, is, above all, an abstract image shaped by thought in close relation to words and language. It is, therefore, a generalized image that encompasses not the characteristics of any isolated object, but the characteristics of an entire class of objects.

Regarding the scientific concept (in this case, the chemical concept) as a form of thought, the responses do not reflect the idea that concepts establish new relations that allow for new knowledge, such as judgments and reasoning, as highlighted in dialectical logic.

> It is interesting to notice, with some frequency, the establishment of a relationship between a *definition* and *something*. This can be explained by the fact that undergraduates understand the term concept as the *definition of something* (*one thing*), as demonstrated in the following responses:
>
> It is a *definition* established regarding *something* concrete and/or abstract (undergraduate 11, 2023).
>
> […]
>
> It is the theoretical *definition of something* (undergraduate 13, 2023).
>
> […]
>
> The concept is a *definition of something* (undergraduate 16, 2023).

In the undergraduates' responses, the term *definition* appears in 28 co-occurrences, according to Table 2. According to dialectical logic, the concept is differentiated from its definition. Núñez and Bandeira (2024) and Núñez and Silva (2020) point out that people, including teachers, often confuse what concepts (understood as forms of thinking) are with logical operations of thought, such as definition, and teach according to this mistake, disregarding that it only reveals the content of the concept, and not its entirety.

The concept, as explained by Núñez and Silva (2020), is a form of abstract thought and reflects the essential aspects of a class of objects. The definition is a logical operation that reveals the content of the concept and establishes its meaning through verbal language, ensuring its precision. The concept is a mental reflection, and the definition is its verbal formulation. The Chemistry teacher must be aware of the specificities of the chemical concept and the difference between this form of thinking and other thought operations, such as definition.

Reducing the concept to its definition, it seems, may be associated with processes of memorizing the meaning of the concept, rather than more elaborate thought processes.

Several studies, such as those by Travieso and Hernández (2017) as well as Núñez and Silva (2020), highlight this difficulty, not only among students at basic and university levels but also among teachers. According to Núñez and Silva (2020), some teachers include forms of thinking, such as logical operations, including the definition of concepts, in their lessons. However, many develop these incorrectly, lacking awareness of the logical relationships between concepts and their definitions. This situation may be partly associated with the limited attention given to the nature of scientific concepts in science education when the focus is on mathematical formulas, false problems, and the reproduction of concept definitions, as argued by Oviedo and Perez (2018).

In general, it can be stated that, at the core of the undergraduates' representations of what a scientific concept is, in the context of chemistry teaching, is the idea that it is something they relate to the definition.

In the second question of the pedagogical test, the undergraduates were required to define a concept from Chemistry, which allowed for the revelation of their knowledge on the topic. Table 3 presents the categories of the analysis of the responses that appeared most frequently. It can be seen that 39.1% of the undergraduates correctly define a Chemistry concept, indicating that they provide clear, appropriate, and distinct definitions. However, in 13.0% of the responses, the definition is incorrect according to logical form, and in 32.6%, it is incorrect regarding Chemistry content. Additionally, 15.2% do not define a concept but refer to a law or principle of science, which constitutes more complex systems of chemical concepts.

Table 3 – Definition of the Concept

Response categories	Percentage
Correct (appropriate, clear, distinct)	39,1
Incorrect (with respect to logical form)	13,0
Incorrect (with respect to Chemistry content)	32,6
Does not define a concept	15,2

Source: The authors (2023)

It is important to highlight that the correctly defined concepts are limited to a specific content (number of essential characteristics) and were also expressed with linguistic simplicity (although they are clear, appropriate, and distinct) in the explicitness of their logical structure. Among those presented, there is no structuring concept of Chemistry. The most frequently presented were definitions of the concepts of base, mass and acid, as illustrated by the following example.

> Arrhenius acid. An acid is a substance capable of increasing the concentration of H+ ions in an aqueous medium (undergraduate 7, 2023).

In this example, there is clarity, as it provides a mental image that includes all the essential characteristics of the class it represents, and it is also possible to identify any acid included in that class. The criterion of distinction is present in this definition because it clearly discriminates the characteristics that are essential to the referred concept.

Concepts were considered incorrect according to logic if they fundamentally did not present correct definitions and, therefore, were neither clear nor appropriate. Additionally, it was evident that the undergraduates produced simple texts, which included both necessary and sufficient characteristics of the definition as well as other characteristics not essential to the class in question. Two examples of these incorrect concepts are:

> Science that studies natural phenomena. It helps to elucidate the composition of matter, its benefits, and handling (undergraduate 36, 2023).
>
> […]

> Chemical bonds: these are interactions established between two or more atoms to form molecules, or in the case of ionic or metallic bonds, atomic aggregates organized to constitute the basic structure of a substance (undergraduate 46, 2023).

The data confirms a certain misunderstanding of what a scientific concept is according to the framework we rely on for the analysis. By including non-essential characteristics to define a chemical concept, the undergraduates disregard the idea that a scientific concept reveals the essence of the class it represents, rather than the common or general aspects, according to dialectical logic.

The incorrect definitions regarding Chemistry content, presented by 32.6% of the undergraduates, relate to conceptual errors, that is, content incompatible with the knowledge of Chemistry as a scientific discipline. Examples of these definitions include:

> Ionization energy is the energy required to remove an electron from a gaseous atom (undergraduate 28, 2023).
>
> […]
>
> Matter is everything that has mass and occupies a space (undergraduate 34, 2023).

Scientific concepts should be clear, appropriate, and distinct, as the shared understanding of their meanings as well as rigor and objectivity in the theoretical framework to which they belong depend on this. These definitions show conceptual errors widely highlighted by various studies, including those by Gilmanshina (2005b), such as stating that an atom is in the gaseous state and confusing matter with substance.

In the case of 15.2% of the undergraduates, the concept is confused with a law or a principle, thus presenting a lack of clarity regarding the epistemological nature, which reveals difficulties in understanding Chemistry as a science. This situation has been pointed out by several studies that reveal the difficulties of students and teachers in understanding sciences and their nature, as well as the epistemological nature of concepts (Taber, 2019). By confusing, in the logical sense, the concept, as a basic form of logical-verbal thought, with the concepts of law or scientific principle, a logical error is observed, as the epistemological status and the relationships between the concept, law, and scientific principle in Chemistry are disregarded. This is manifested in the following responses:

> Law of conservation of mass: all matter present in the reactants is conserved in the products (undergraduate 41, 2023).
>
> […]
>
> The uncertainty principle states that if you know the speed of the atom, you cannot know its location and vice versa (undergraduate 8, 2023).

With the third question of the pedagogical test, we aimed to find out, in the opinion of the undergraduates, when it can be said that students have mastery of a scientific concept in the context of learning in Chemistry classes. The analysis of the responses can contribute to understanding the undergraduates' knowledge of what a chemical concept is and when, to some extent, they relate it to its functions in teaching. Table 4 presents the most common categories found in the undergraduates' responses.

Table 4 – When the student has mastery of the scientific concept

Response category	Percentage
When they use the knowledge in practice	39,1
When they define the concept or characterize it	21,8
When they solve problems	21,7
When they can explain the concept or phenomenon	19,5
When they identify the concept	4,3
When they associate the concept with words	4,3

Source: The authors (2023)

It can be observed in Table 4 that, for 39.1% of the undergraduates, the student appropriates the scientific concept when they use it in practice. However, due to the limited responses, they do not delve into the meaning of practice in this application. This view is very present in the ideas of many teachers, as argued by Oviedo and Perez (2018). The tendency, in this sense, is to associate the learning of the concept with its application without relating it to the development of forms of scientific thinking, which, in turn, is a privileged source that fosters the student's integral development, according to Galperin (2023). For 19.5% of the undergraduates, conceptual appropriation occurs when one is able to explain the concept, and for 21.8%, when one knows how to define the concept.

In relation to the mastery of the concept, when one is able to define it, it is important to emphasize that, in the EHCP, this logical operation of thought alone is not desirable, as it is considered one of the stages in the complex processes of thinking with scientific concepts. When this process is limited to the definition, as Vygotsky warns (2009, p. 54): '[...] the concept is removed from its natural relationship, in a stagnant form, outside the connection with the real thinking processes in which it arises, is discovered, and lives.' In the same sense, Núñez and Silva (2020) have extensively discussed that defining the scientific concept is an initial stage of its appropriation by students, in which its content and structure are established. Subsequently, the concept must be integrated into the content of thought in the approach and resolution of problem situations, as highlighted by Galperin (2023).

Therefore, mastering a concept is not just about knowing and reproducing its definition or the verbal language by which it is expressed, as Hedesa (2014) emphasizes, but also about understanding it by consciously applying it in the solution of productive or creative tasks, which requires thinking with that concept. In this direction, Leontiev (2021) warns that a concept is mastered when one knows how to act conceptually with it, that is, practice is conceptual.

Of the total undergraduates, 21.7% associate the mastery of the concept with problem-solving. The responses do not provide information that allows for a better understanding of what solving a problem means to them. Consequently, the answers remain at the declarative level, making this result a subject for exploration in other research.

To illustrate the previous analyses, some of the undergraduates' responses are presented:

> When the student demonstrates that he knows how to apply the concept seen in a situation by solving a problem. From there, we see that he has not memorized the concept, but has learned it and can use it for a purpose (undergraduate 21, 2023).

> […]
> From the moment the student defines the concept and confidently presents its applications (undergraduate 8, 2023).
> […]
> When the student can reproduce what was taught in his own words (undergraduate 3, 2023).

It is observed in the established categories and the responses of the undergraduates the absence of references to the mastery of concepts related to the development of students' chemical thinking as being capable of contributing to the formation of an integral personality, something essential in the EHCP approach. In this approach, it is understood that, with the appropriation of concepts, qualitatively different ways of thinking and acting with them are also formed and developed in the sense highlighted by Vygotsky (2009). The learning of scientific concepts by students in the school context implies the ability to make sense of them according to the meanings established by the sciences, to understand them well, and to generalize them, which, in turn, leads to the establishment of new relationships with other scientific concepts in a complex web of meaning relationships.

According to Hedesa (2014), mastering a chemical concept involves using it not only to establish new conceptual relationships (chemical reasoning), derived and opposed for analysis, but also to explain concrete phenomena, in a transition from the abstract to the concrete, which does not appear in the responses of the undergraduates.

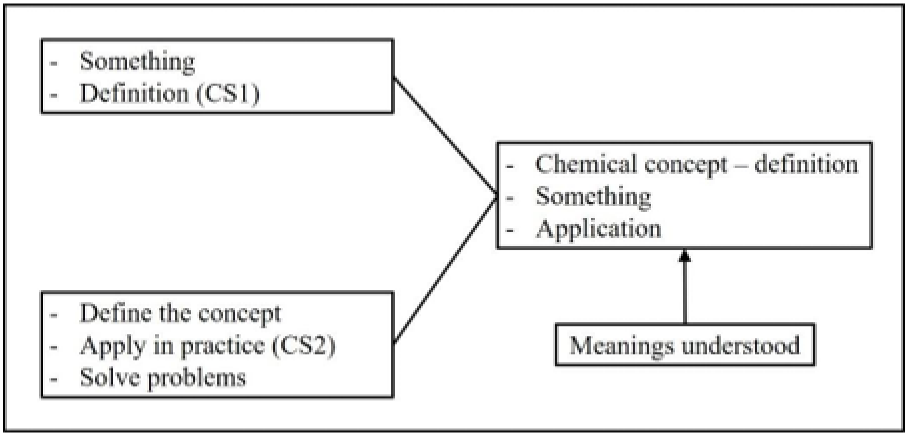
Considering chemical concepts as forms of chemical thinking in the elaboration of judgments and reasoning in Chemistry, it is observed in the responses the absence of these aspects when referring to the mastery of the chemical concept by the students. From a dialectical logic perspective, this is an important aspect in understanding what a chemical concept is for the teachers of this subject. Results of this type have been obtained by authors such as Taber (2019), Núñez and Silva (2020), Núñez and Bandeira (2024), who attribute this situation to a teaching approach that is neither explicit nor conscious of logical (formal and dialectical) thinking in the formation of Chemistry teachers.

In the responses, there is no mention of the processes of elaborating new concepts (knowledge) as a way of learning new content. Essentially, the aspect of applying concepts is revealed. It is noticeable that the undergraduates separate the learning of scientific concepts from their application, which, to some extent, excludes the relationship between the emergence of scientific concepts in problem-solving processes and highlights the erroneous idea, in the epistemological sense, that concepts arise first and problems come later, to be applied afterward, as explained by Talízina (2023). Understanding this relationship is an important element in the epistemological comprehension of sciences with implications for teaching.

Finally, in the pedagogical test, the undergraduates were asked if, during their training, in any of the subjects (curricular components), aspects related to what a chemical concept is and its nature were discussed from any perspective. The response was unanimous: everyone answered that this content was not part of their training.

In order to infer the most prevalent meanings in the undergraduates' responses regarding what a chemical concept is in the context of its teaching in the school setting, two semantic fields were developed: CS1 (related to representations) and CS2 (related to professional knowledge), which were triangulated as shown in Figure 03..

Figure 3 – Semantic fields of the undergraduates' meanings of what a chemical concept is



Source: The authors (2023)

From the triangulation of the presented responses, a general meaning (which does not exclude less prevalent singularities) can be inferred from the meanings attributed by the undergraduates to chemical concepts, as being something – one thing, confusing these with their definition and applying them in processes, with emphasis on problem solving.

Conclusions

The analysis of the undergraduates' responses in the pedagogical test highlighted important aspects regarding the epistemological understanding of chemical concepts in the context of their teaching in school. The responses revealed that, in general, they do not refer to concepts as mental images but rather as something or one thing. A significant number of undergraduates confuse the concept with its definition. Relevant issues, such as the relationships of chemical concepts with students' chemical thinking, were absent from the responses.

It was evident that a small number of undergraduates correctly defined a concept according to the requirements of dialectical logic, while others made conceptual errors of a logical nature, and even confused scientific concepts with scientific laws or principles. This may reveal inadequate epistemological and conceptual knowledge in relation to the EHCP framework. It was interesting to observe that, in general, they declaratively attributed problem-solving as the essential indicator of students' appropriation of concepts. All these results highlight a certain lack of knowledge of the possibilities of dialectical logic as a framework for the functions of concepts in chemical thinking.

The obtained results can contribute to considering the inclusion of the EHCP, concerning the nature of chemical concepts, in the curriculum for training Chemistry teachers, as professional knowledge for teaching and learning this subject in basic education.

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