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Article

Molecular misconceptions: A cross-national study on university students' understanding of the mole concept

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Abstract: This study investigates university students' understanding of the mole concept and its implications for chemistry education, highlighting the critical role of mathematical education. A questionnaire was administered to 303 students from universities in Panama, Mexico, Cuba, Chile, and Spain. The results reveal that only 29.7% of participants recognize the mole as a fundamental unit, while 20.8% confuse the amount of substance with a non-existent "Chemical System." Only 18.5% correctly identified the substance quantity symbol as "*n*" and 32.7% were aware that Wilhelm Ostwald introduced the term mole, indicating deficiencies in historical knowledge. The significance of these findings highlights major misconceptions and gaps in both conceptual understanding and historical knowledge, underscoring the urgent need for revised teaching strategies. Addressing these issues is crucial for bridging the gap between theoretical knowledge and practical application, thereby enhancing instructional methods and optimizing chemistry education to improve students' comprehension of fundamental concepts.

Keywords: quantity of substance; concept of mole; unit of measurement; historical knowledge; system of units; education in chemistry

1. Introduction

The term mole was first used in 1886 by the German chemist-physicist Wilhelm Ostwald, who defined the term as "the mass in grams of a substance numerically equal to its normal weight or molecular weight." Ostwald introduced the term "quantity of substance"; however, this term was used to refer to mass or quantities of masses (Furió-Mas et al., 2007, Hanson, 2019).

The quantity of substance whose symbol is n is defined as proportional to the number of specified elementary entities N in a sample (BIPM, 2023). The unit of the quantity of substances is called a mole, and its symbol is mole. When the mole is used, elementary entities must be specified and may be atoms, molecules, ions, electrons, other particles, or specific groups of such particles (14th General Conference on Weights and Measures (GCPM, 1971). In 2018, at the 26th meeting of the GFCM, the definition of the kilogram based on the mass of the cylindrical platinum-iridium prototype preserved in Paris was repealed. At this meeting, resolution 1 of the 26 GFCM was tested, where the definition of the kilogram and the mole was changed. These new definitions entered into force on 20 May 2019.

One of the essential problems of chemistry is the fact that its content is studied on three levels (macroscopic, submicroscopic and symbolic), of which only one of the three is directly accessible to the senses (Gulacar et al., 2020), they confirm that by establishing that similar vocabularies have emerged around the mole such as: particles, molarity, molar volume, molar mass, molecular mass and atomic mass, among others.

Studies carried out during admissions to the Faculty of Natural, Exact Sciences and Technology (FACINET) of the University of Panama between 2021 and 2023, within the framework of the Faculty Renewal Program, revealed that the retention rate at the end of the first year of studies varies between 20% and 40% depending on the career. This indicates a high rate of shelling in the first year (Fiad and Quiroga, 2010). Different authors have pointed out that the problems associated with the teaching and learning of Natural Sciences, particularly in Mathematics, Physics and Chemistry, are reflected in the low academic performance at both the secondary and university levels, as well as in the decrease in students who choose related careers in higher education (Bär, 2010; Merino de la Fuente, 2002; Moss and Pabari, 2010; Ratto, 2012).

For Mazzitelli (2013), these problems may be related to perceptions of science, its teaching and learning. The problem covers aspects related to students and teachers, both those in practice and those in initial training. In the basic sciences, the measurement of different quantities is essential and quantities such as mass, length, volume and time are used on a daily basis (Reboiras, 2006). These magnitudes are tangible and familiar to the students, allowing them to dimension what is 1 kg of sugar or 100 cm of a strip of paper. However, the quantity of substance, which refers to the number of particles present in a sample (atoms, molecules, ions, or electrons) and whose unit is the mole, presents greater challenges in understanding.

This concept is difficult to address due to its complexity and the difficulty of relating it to everyday examples, which generates epistemological obstacles among secondary school students (Furió-Mas et al., 2002). The teaching of this concept is usually limited to theoretical, often erroneous, elements where the quantity of substance is incorrectly considered as a quantity of mass or simply as the number of chemical units (Furió-Mas et al., 2002).

Didactic research has repeatedly pointed to learning difficulties around the concept of mole (Dierks, 1981; Vorsah and Adu-Gyamfi, 2021). Students lack a clear scientific conception due to epistemological and didactic deficiencies in their usual teaching (Gabel and Bunce, 1994). Many students mistakenly identify the mole with a mass, a volume, or a number of entities, and do not know the meaning of the magnitude or quantity of the substance, avoiding its handling and not identifying the mole as a unit (Krishnan and Howe, 1994; Staver and Lumpe, 1995; Schmidt, 1994). This confusion is frequent, especially when differentiating between molar mass and molecular mass (Furió-Mas et al., 1993). In addition, Avogadro's number or constant, which refers to the number of particles in any mole of substance, raises questions such as why substances with different molar mass have the same number of particles, and how this immeasurable quantity can be verified (Azcona, 1997; Furió-Mas et al., 2002;

García Sepúlveda, 2010).

The concept of mole is crucial for first-year chemistry students, as understanding it is necessary to solve stoichiometry problems (Kolb, 1978). The learning of scientific concepts requires the simultaneous development of methodological competencies and teaching consistent with this objective (Huey et al., 2019; Gil et al., 1991; Millar, 1989). Students of the Chemistry careers at the Faculty of Natural Sciences, Exact Sciences and Technology (FACNET) are no exception. The records of diagnostic evaluations of the admission exam between 2022 and 2023 show that between 89% and 92% of students make conceptual errors regarding the mole, and do not know how to differentiate it from molar mass, molar volume and Avogadro’s constant. This shows the need for a revision in teaching methodology to improve the understanding of these fundamental concepts.

The concept of the mole is fundamental in chemistry; however, its understanding among university students presents significant challenges, including misconceptions and a lack of connection with prior knowledge. To address these challenges, two theoretical approaches provide a robust framework for improving the teaching of the mole: David Ausubel’s Theory of Meaningful Learning and Lev Vygotsky’s Social Constructivism.

Ausubel (1968) argues that learning is more effective when students can relate new information to their prior knowledge. In the context of the mole concept, this means that students must have a solid foundation in units of measurement and chemical quantities before tackling this complex idea. By establishing these connections, learning about the mole becomes more meaningful, enabling students to understand not only the definition of the mole but also its practical application in chemistry. Ausubel emphasizes the importance of organizing teaching in a way that fosters this relationship between prior and new knowledge, which is crucial for developing a deep understanding of the mole.

Vygotsky (1978) emphasizes the role of the social and cultural environment in learning. According to his theory, learning is a socially mediated process where interaction with others, as well as the institutional context, plays a key role in the internalization of complex concepts like the mole. Vygotsky suggests that knowledge is constructed through collaboration and communication, indicating that the teaching of the mole could be improved by creating collaborative learning environments. These environments allow students to discuss and reflect on their ideas together, facilitating a deeper understanding through mutual support and joint knowledge construction.

Student success is related not only to their intellectual abilities but also to the procedures or strategies they have developed to achieve their learning objectives. Motivation to learn plays a fundamental role in any field of study, and psychological research has shown that without motivation there is no learning (Pozo, 1993). It is necessary to understand that lack of motivation is also a consequence of the education that the student receives and how he or she is taught (Pozo and Gómez Crespo, 1998).

Motivation can be classified as intrinsic or extrinsic and is not a unitary process but encompasses diverse components (Nuñez and González-Pumariega, 1996). Therefore, the design of virtual educational environments, such as virtual chemistry laboratories, can be an appropriate strategy to improve the understanding of concepts such as the mole, increasing the methodological variety and promoting the student's protagonism in the learning process (Cataldi et al., 2011; Rosado and Herreros, 2009).

This research points to the institutional, personal, and academic factors that influence university student learning from the chemical concept of the mole, so the relationship between the various planes is examined (IDB, 2024). The horizontal plane is made up of the cultural, political and economic spheres, while the vertical plane consists of the macrosocial and individual complexity and its influence on the person. In a report issued by the World Bank (Furió-Mas et al., 2002), it is indicated that Panama is the fourth country in Latin America with the highest student dropout, this corresponds to 30% of the university student population. Bolivia holds the first place on the list with 48%, followed by Colombia with 42% and Ecuador, with 32% of university dropouts.

In this study we ask ourselves if a student at a higher level once he has passed a subject of general chemistry: does he know the concept of the mole? Do you know how to differentiate between quantity of substance and mole? Do you know the historical evolution that the concept of the mole has undergone? To what extent does limited knowledge of essential concepts of chemistry affect the construction of other terms at higher educational levels?

2. Materials and methods

This is a quantitative and descriptive research with a correlational design. The dependent variable is the knowledge about the mole and quantity of substances, and the independent variable is the conditioning factors of knowledge, understood as institutional, personal and academic elements. A non-probabilistic convenience sampling was used for convenience of the universe of students who have passed at least one general chemistry course from the universities of Panama, Mexico, Cuba, Chile and Spain.

A sample of 303 students was obtained while maintaining the confidentiality of the respondents. The sample was selected through convenience and purposive sampling from several universities in five countries, focusing on students enrolled in introductory chemistry courses. The instrument was prepared, validated, and applied to these students, consisting of five sections with a total of 44 elements (see annex 1). The sections are as follows: I. Sociodemographic data of the participant (7 items). II. Knowledge of the mole and quantity of substance (14 elements). III. Institutional factors (5 elements). IV. Personal factors (11 elements). V. Academic factors (7 elements). The surveys were administered both in person and online, ensuring students had been sufficiently exposed to the material, with the diverse sample reflecting the general student population, allowing for meaningful insights into misconceptions and cross-national trends.

A reliability analysis of the test and the study factors was performed, which resulted in a Cronbach's Alpha Global of 84.1%, which indicates a good internal consistency of the instrument. The quantitative data were segregated by universities and analyzed using jamovi 2.3.28 software. From here, percentages and measures of central tendency were obtained. To study the relationship between the variables investigated, descriptive statistics will be used.

3. Results and discussion

This study highlights the importance of understanding the mole concept among university students and identifies areas where misconceptions persist. The findings indicate that while students predominantly possess a scientific conception of the mole, confusion arises in distinguishing between magnitude and unit of measurement. A significant portion of students mistakenly associates the mole with molar mass or gram, rather than recognizing it as a unit for the amount of substance. This suggests a need for educators to emphasize the distinction between these concepts and to clarify that the symbol for the quantity of substance is "*n*".

Additionally, the results reveal that the teaching of the mole often focuses on practical applications rather than the underlying conceptual and historical context. To enhance comprehension, it would be beneficial to integrate more practical and contextualized teaching methods that connect the mole's symbolic representation to its real-world applications.

3.1. Sociodemographic aspects

The participating universities were: University of Panama (59.1%); Autonomous University of the State of Hidalgo (Mexico) (19.5%); University of Cuba (10.2%); International Maritime University of Panama (UMIP) (6.6%); Catholic University of Temuco (Chile) (2.3%); Universities in Spain (2.3%). According to sex, 44.0% were men and 55.0% were women, the rest did not answer this question. In relation to age, 39.0% were 17 to 19, 40.0% were 20 to 22 and the rest were over 22 years old. 75.0% of students come from public schools.

3.2. Mole knowledge and quantity of substance

This section corresponds to questions related to the knowledge of the mole. **Figure 1** shows the percentage that was obtained based on the correct answers in the survey.

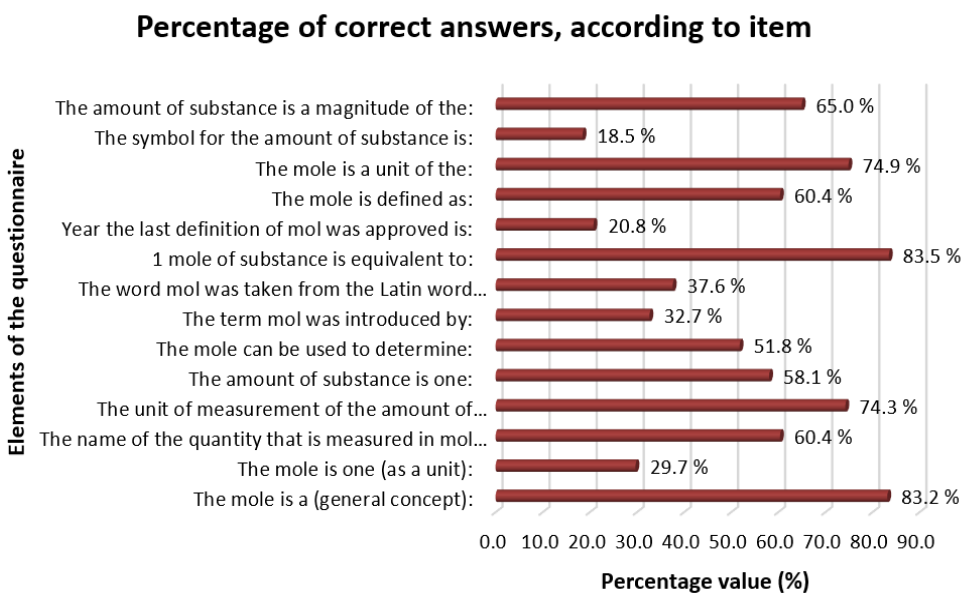

Figure 1. Correct answers according to item.

The questions with the highest percentage of correct answers are:

1) 1 mole of substance is equivalent to: 6.022×10^{23} elementary units (83.5%).
2) The mole is a (general concept): unit of measurement (83.2%).

The high percentage of correct answers in these questions is probably since both fundamental and basic concepts in chemistry are introduced at the basic levels of education, in addition, Avogadro's number is used in stoichiometric calculations; that is, students remember concepts that will be used in practice. On the other hand, the questions with the lowest percentage of correct answers are:

1) The symbol for the amount of substance is: *n* (18.5%).
2) The year the last definition of the mole was approved is: 2019 (20.8%).

When analyzing the first question, we found that the largest number of students (72.8%) incorrectly indicated that the symbol for substance was mole. Hence, the low percentage of correct answers about the symbol of the quantity of substance could be due to the confusion between unity, symbol and magnitude. So, it is possible that the international system of measurement has not been emphasized enough in class or that students may have learned these basic concepts without having internalized the symbols that represent them.

Understanding the history of science and specifically that of the mole helps students understand how the concept developed, its importance in chemistry today and awakens the interest in solving problems that we face today. 32.7% of the students surveyed indicated that they were clear that the term mole was introduced by Wilhelm Ostwald, however, only 20.8% answered correctly that the year the last definition of the mole was approved was in 2019, this indicates that although chemical history is taught in the first years of education, there is little interest in updating these concepts, perhaps because it is not of educational interest or because of a lack of dissemination by teachers (Quijano Cedeño and Navarrete Pita, 2022).

3.3. Institutional factors

In this section, we inquired about classrooms and laboratories and how stimulating they were to encourage the study of chemistry. 32.3% partially agreed with. This question is relevant, given that various studies indicate that infrastructure can impact the teaching-learning process. Based on the above, we can consider that an important sector of students does not visualize the facilities of their institution as places that stimulate them to dedicate time to study.

In relation to the process of accompaniment and relationship with tutors and mentors, it was questioned whether the chemistry teacher clarifies doubts, 32.2% agree that teachers clarify doubts, while 28.6% partially agree. More than 50.0% of the students surveyed indicated that they agree or completely agree with the support provided by their institutions for their academic training.

In examining the impact of institutional factors on students' engagement with chemistry, it's clear that the environment plays a pivotal role. The finding that 32.3% of students only partially agree that their classrooms and laboratories are stimulating for the study of chemistry is concerning. This suggests that a significant portion of the student body perceives the physical infrastructure as lacking in its ability to motivate or inspire them to invest time in their studies. This aligns with broader educational research, which emphasizes that well-designed, resource-rich environments can significantly enhance the teaching-learning process. When students feel that their learning spaces are uninspiring, it can lead to reduced motivation and engagement, which in turn affects their academic performance and interest in the subject.

Moreover, the interaction between students and faculty is another critical institutional factor. The survey revealed that while 32.2% of students agree that their chemistry teachers effectively clarify doubts, and 28.6% partially agree, this leaves a substantial proportion of students who may feel that their academic needs are not being fully met. This highlights the importance of effective communication and support from educators, which is crucial for fostering a deeper understanding of complex subjects like chemistry. Despite these challenges, it's encouraging that over 50.0% of students express satisfaction with the support provided by their institutions, indicating that there is a foundation upon which to build more effective teaching strategies and a more supportive learning environment. However, these results also underscore the need for continued improvement in both the physical and interpersonal aspects of the educational experience to ensure that all students are adequately supported in their academic journey.

3.4. Personal factors

Various studies place personal components as an important part of the factors that strongly affect the academic performance of students. It was found that 73.9% of respondents indicated that they agree or completely agree with the fact that chemistry is a subject that stimulates their motivation and on which they find it easy to concentrate. 64.7% of those surveyed indicated that they had initiative in their studies. Depending on the personal and family situation, the question was whether both factors facilitate the study of chemistry, the highest percentage (33.9%) was obtained with the answer; Partially agree and 42.2% strongly agree that stress affects performance in chemistry. In this context, it is important to note that the influence of the family environment, and the establishment of social or interpersonal relationships, have a positive impact on academic success. Chemistry requires problem solving, interpretation, and critical thinking, and a high level of stress can interfere with the ability to think logically and clearly.

73.9% of those surveyed completely agreed and agreed with the item that alludes to the supportive relationships they have with their classmates. This aspect constitutes a positive factor that contributes to persistence in the course and even more so when 43.9% responded that they partially agree with the item that inquiries about how consistent the respondent is in their study habits. Relationships with their classmates are more relevant, as 32.3% responded that they partially agree when they classify their experience in chemistry as a rewarding one.

In this section on personal factors, there is a tendency to recognize disagreement with assuming that students have good time management (averages close to 3 points on the 5-level Likert scale). The same is observed when it comes to affirming that they have well-defined study habits, however, both factors do not define having or knowing about the mole.

On the contrary, the factors that correspond to: It is easy for me to concentrate on chemistry, and I have initiative in my chemistry studies and my personal situation seem to be two factors that are related to having or not having knowledge about the mole ($p < 0.050$). The personal factor: My personal and family situation facilitates the study of chemistry can be considered important and the object of reasoning ($p = 0.054$), see Annex II.

3.5. Academic factors

This section seeks to determine how much impact the academic factor has on the integration of scientific knowledge alluding to the mole. To this end, 7 items were included aimed at determining, among other aspects: teaching methods, prior knowledge in chemistry, perception of the usefulness of the subject, and their own skills in analysis and critical thinking (Huey et al., 2019).

The survey items addressed several critical areas:

Teaching Methods: Evaluating how different pedagogical approaches affect students' understanding of the mole. This includes assessing the effectiveness of instructional strategies and whether they support the learning of fundamental concepts.

Prior Knowledge: Determining whether students possess the foundational knowledge necessary to grasp the concept of the mole and build upon it to understand more complex chemical concepts. This includes evaluating the adequacy of chemistry education received during high school.

Perception of Usefulness: Understanding how students perceive the relevance of learning about the mole in their broader education and its application in real-world scenarios.

Analytical and Critical Thinking Skills: Assessing students' self-reported abilities in analysis and critical thinking and how these skills contribute to their understanding of the mole and chemistry in general. The elements addressed the topics related to the prior knowledge that is required to understand the concept of mole in chemistry, specifically knowing the concept of mole to later address more complex concepts, and whether they considered having acquired previous knowledge in high school.

The following figure (**Figure 2**) shows the average as a function of academic factors. To interpret the averages, it is necessary to keep in mind that on the Likert scale, 5 completely represents disagreement. The closer the average is to 1, the more you agree with what is proposed, the opposite is when it moves away from one, it indicates a higher level of disagreement. Regarding the students who indicated that they had acquired sufficient knowledge about chemistry in secondary school, that is, who answered that they completely agreed and agreed, 58.7% came from private schools, and 38.5% came from public or official schools (**Figure 2**).

According to the *t*-student test, there are statistical differences between the levels of responses or perception between those who have and those who do not have knowledge, in relation to having adequate skills in analysis and thinking. That is, having or not having knowledge about the Mole is strongly related to the skills of analysis and thinking.

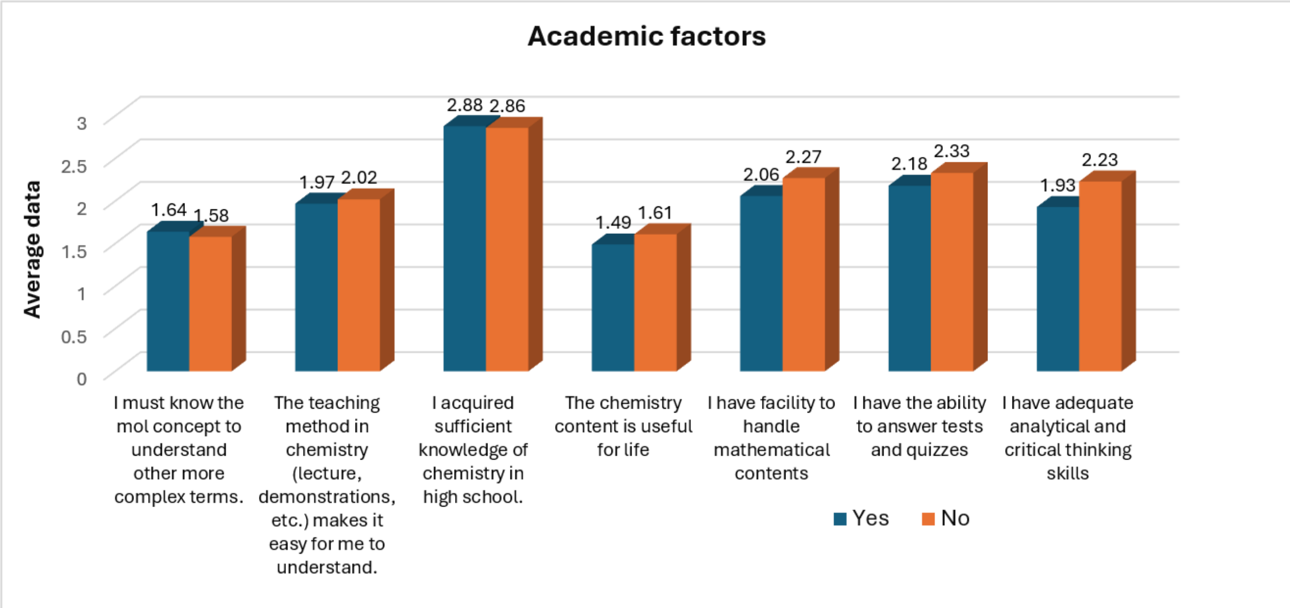

Figure 2. Academic factors analyzed using the Likert scale.

Another factor that could be considered, although it does not show statistical significance less than 0.05, but does show less than 0.1, is the factor: I have an ability to handle mathematical content. This factor must be reviewed in the course content and reinforced. On the other hand, students recognize that they bring deficiencies from school (average responses of almost 3 points on a scale of 5) both in those who have or do not have some knowledge of the mole.

Having adequate skills in analysis and thinking is an important factor since it is significantly associated with the other academic factors ($p < 0.01$), with the exception of the factor: I acquired sufficient knowledge of chemistry in school.

Finally, the academic factor brings together the general, essential skills in the chemistry student to achieve successful learning. Over 88.0% of those surveyed recognize the importance of the concept mol as fundamental to understanding other more complex chemistry terms. The answer to the item that explores the knowledge of chemistry acquired in secondary school registered the highest percentage of responses in the partial agree option (26.4%). While 31.0% of the respondents responded that they disagreed or completely disagreed with the sufficiency of the knowledge of chemistry acquired at the secondary level. 86.5% of the students surveyed completely agreed or agreed that knowing about chemistry is useful for life. While 64.0% indicated that they completely agree or agree with their ability to handle mathematical content.

Once each section was analyzed, correlations were made between the sections of the survey. The first analysis that was carried out was a comparative analysis of the results obtained related to the knowledge of the mole by students from Panama and students from other countries. The results are summarized in **Tables 1** and **2** and it is observed that the percentage distribution in both groups is very similar, that is, there seems to be no difference in terms of the level of knowledge about the mole by Panamanian students versus students from the other countries of the study.

Table 1. Percentage of correct answers about the Mole, by higher education institution.

Question	Correct answers by Institution E.S.					
	Panama		Other universities		Total	
	No.	%	No.	%	No.	%
The mole is a (general concept): (*)	158	79.4	94	90.4	252	83.2
The mole is one (as a unit): (*)	71	35.7	19	18.3	90	29.7
The name of the magnitude that is measured in moles is:	122	61.3	61	58.7	183	60.4
The unit of measurement for the quantity of substance is:	150	75.4	75	72.1	225	74.3
The amount of substance is one:	114	57.3	62	59.6	176	58.1
The mole can be used to determine:	107	53.8	50	48.1	157	51.8
The term mole was introduced by:	66	33.2	33	31.7	99	32.7
The word mol was taken from the Latin moles which means:	71	35.7	43	41.3	114	37.6
1 mole of substance is equivalent to:	172	86.4	81	77.9	253	83.5
Year the last definition of the mole was approved is: (*)	34	17.1	29	27.9	63	20.8
The mole is defined as:	120	60.3	63	60.6	183	60.4
The mole is a unit of: (*)	157	78.9	70	67.3	227	74.9
The symbol for the amount of substance is: (*)	28	14.1	28	26.9	56	18.5
The amount of substance is a magnitude of:	132	66.3	65	62.5	197	65.0

1 (*) significant differences are evident ($p < 0.05$).

Table 2. Percentage of correct answers, comparison between Panama and the other participating countries.

Percentage of Correct Answers	Institution (Country)	
	Panama	Other countries
Under 60	65.8	63.5
61–70	13.6	11.5
71–80	17.6	21.2
81–90	2.5	2.9
91–100	0.5	1.0
Total	100.0	100.0

* Comparison of Correct Answer Percentages: Panama vs. Other Participating Countries.

An analysis carried out according to the year of entry, comparing with the most novice who entered in 2022 and 2023, shows that in all cohorts the distribution of correct answers is very similar; that is, the highest percentages are concentrated in less than 60 points out of 100 answered correctly. About 8.0% scored above 80 percentage points in the 2022–2023 cohorts and before 2022. In the case of those not specified, the situation is somewhat different, since the total number of students is below 80 percentage points in terms of correct answers in the mole knowledge test, see Annex III.

This research underscores several key insights into students' understanding and misconceptions surrounding the concept of the mole. While a significant portion of students demonstrate a foundational scientific grasp of the mole, there are critical areas of confusion that warrant attention. These misconceptions are particularly evident in the students' differentiation between magnitude and unit of measurement. Many students mistakenly associate the mole with molar mass or grams, rather than recognizing it as a fundamental unit for measuring the amount of substance. This confusion extends to the symbols used, with students frequently mixing up the symbol for quantity of substance ("*n*") with other units. To address these issues, educators must emphasize that magnitude refers to a property of a phenomenon, body, or substance that can be quantitatively expressed with a number and a reference, and that the mole, as a unit, should be clearly distinguished from related concepts.

The significance of this research lies in its exploration of students' understanding of the mole, a fundamental concept in chemistry. By identifying common misconceptions and gaps in knowledge, this study sheds light on areas where educational approaches can be refined. A strong grasp of the mole and related concepts is essential for students as they progress in their scientific education, making this research crucial for informing teaching strategies that can better prepare students for advanced studies and professional careers. The findings underscore the need for a more contextualized and historically informed pedagogy that not only teaches the technical aspects of the mole but also connects them to broader scientific principles and real-world applications.

4. Discussion

The results of this study emphasize the need for greater clarity in teaching the mole concept within university chemistry curricula. While most students demonstrated a solid understanding of fundamental concepts, such as the equivalence of 1 mole to 6.022×10^{23} elementary units, confusion persists when it comes to differentiating the mole's magnitude as a quantity of substance and its use in calculations related to molar mass.

One of the most concerning findings was the low percentage of correct answers regarding the symbol for the quantity of substance ("*n*") and the year of the most recent definition of the mole (2019). This indicates a gap in both historical and symbolic knowledge, which is essential for a comprehensive understanding of the subject. The lack of emphasis on these aspects may contribute to students' confusion between basic concepts like unit, symbol, and magnitude.

Additionally, the analysis of institutional factors revealed that a significant portion of students do not perceive their university facilities as adequately stimulating for the study of chemistry. This finding aligns with previous studies suggesting that educational infrastructure can impact the teaching-learning process. Similarly, the perception of insufficient support from professors could also be limiting academic development in this area.

In analyzing the common misconceptions and varying levels of understanding of the mole concept among university students across different countries, it becomes evident that these issues are deeply rooted in how students relate new information to their existing knowledge base. David Ausubel's Theory of Meaningful Learning suggests that for students to fully grasp the concept of the mole, they must be able to connect it meaningfully to what they already know about units of measurement, chemical quantities, and stoichiometry. However, many students struggle because their foundational knowledge is often fragmented or superficial, leading to misconceptions such as confusing the mole with the mass or failing to understand its role as a bridge between the microscopic and macroscopic worlds in chemistry. To enhance comprehension, teaching methods must prioritize building strong conceptual foundations and explicitly linking new content to students' prior knowledge. This approach not only clarifies the mole concept but also fosters a deeper, more durable understanding.

Additionally, Lev Vygotsky's Social Constructivism highlights the importance of the social and cultural context in learning, suggesting that the institutional, personal, and academic factors surrounding students significantly influence their understanding of the mole. Misconceptions often arise from isolated learning experiences where students do not have the opportunity to discuss and refine their ideas with peers or instructors. By incorporating more collaborative and interactive teaching methods, such as group problem-solving and peer instruction, educators can create a learning environment that encourages students to articulate their thoughts, challenge misconceptions, and construct a more accurate understanding of the mole concept. These methods, supported by Vygotsky's theory, help students to not only learn from their own experiences but also benefit from the collective knowledge and perspectives of their peers, ultimately leading to a more comprehensive and socially mediated understanding of fundamental chemistry concepts.

Regarding personal factors, the study confirms that motivation and the ability to concentrate on chemistry are crucial for academic success. However, time management and well-defined study habits appear to be areas for improvement for many students. The high correlation between analytical and critical thinking skills with knowledge of the mole suggests that strengthening these competencies could be key to improving the understanding of more complex chemistry concepts.

Finally, the comparison of results between students from different institutions and countries revealed no significant differences in the level of mole knowledge, indicating that these challenges are common across diverse educational contexts. However, the fact that only a small percentage of students achieved scores above 80% on the mole knowledge test suggests that there is room for improvement in both teaching and learning this fundamental concept.

5. Conclusion

This research aimed to investigate university students' understanding of the mole concept, and the findings reveal that while students generally grasp the scientific basis, confusion remains regarding specific aspects. Students often mix up the magnitude with the unit of measurement, particularly confusing the mole with molar mass or grams, and struggle with recognizing the correct symbols for quantities. This indicates a gap between students' theoretical understanding and their ability to apply this knowledge accurately, reflecting the need for better instructional approaches.

The research also sought to explore how institutional, personal, and academic factors influence students' understanding of the mole. More than half of the students reported feeling supported by their institutions, yet personal factors like poor study habits and time management difficulties emerged as obstacles to academic success.

These personal challenges hinder the ability to study chemistry effectively, suggesting that addressing individual learning needs could enhance student performance in chemistry courses.

In line with the study's objectives, the research underscores the importance of improving teaching methods that link conceptual understanding with practical applications. By focusing on meaningful learning, which connects new knowledge with students' existing frameworks, and fostering positive academic environments, educators can help students overcome misconceptions and develop a deeper comprehension of key chemistry concepts like the mole. This holistic approach will contribute to more effective chemistry education at the university level. In conclusion, university students' understanding of the mole concept faces significant challenges, largely due to misconceptions arising from the disconnection between prior knowledge and new information. Applying David Ausubel's Theory of Meaningful Learning, it is crucial for teaching methods to focus on creating clear and meaningful connections between the mole concept and students' existing knowledge, enabling a deeper and more lasting understanding. Additionally, Lev Vygotsky's Social Constructivism emphasizes the importance of a collaborative learning environment, where students can interact and share ideas, facilitating the correction of conceptual errors and the construction of a more robust understanding. By implementing pedagogical approaches that integrate these theoretical frameworks, the comprehension of this fundamental concept in chemistry can be significantly enhanced, contributing to a stronger and more effective education in the discipline.

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References

Azcona, R. (1997). Critical analysis of the teaching-learning of the concepts of quantity of substance and mole. A didactic alternative based on inquiry-based learning (Spanish) [PhD thesis]. Facultad de Ciencias Químicas, Universidad del País Vasco, San Sebastián.

Ausubel, D. P. (1968). Educational psychology: A cognitive view. Holt, Rinehart & Winston.

Bär, N. (2010). What lies behind the fear of hard sciences? La Nación Newspaper (Spanish). Available online: http://www.lanacion.com.ar/1288859 (accessed on 3 March 2015)

Cataldi, Z., Chiarenza, D., Dominighini, C., et al. (2011). Classification of virtual chemistry laboratories and proposal for heuristic evaluation (Spanish). En XIII Workshop de Investigadores en Ciencias de la Computación.

Dierks, W. (1981). Teaching the Mole. European Journal of Science Education, 3(2), 145–158. https://doi.org/10.1080/0140528810030205

Fiad, S., & Quiroga, V. (2010). Difficulties in the learning of General Chemistry I and actions to improve its teaching, within the framework of PACENI (Spanish). En VI Jornadas Internacionales-IX Nacionales de la Enseñanza Universitaria de la Química.

Furió-Mas, C., Azcona, R., & Guisasola Aranzabal, J. (2002). Review of research on the teaching-learning of the concepts quantity of substance and mole (Spanish). Enseñanza de Las Ciencias. Revista de Investigación y Experiencias Didácticas, 20(2), 229–242. https://doi.org/10.5565/rev/ensciencias.3967

Furió-Mas, C., Azcona, R., Guisasola, G., et al. (1993). Students' conceptions of a "forgotten" quantity in chemistry teaching: the quantity of substance (Spanish). Revista de Investigación y Experiencias Didácticas, 11(2), 107–114. https://doi.org/10.5565/rev/ensciencias.4525

Furió-Mas, C., Azcona, R., & Guisasola Aranzabal, J. (2007). Teaching the concepts of substance quantity and mole based on a model of learning as guided inquiry (Spanish). Enseñanza de Las Ciencias. Revista de Investigación y Experiencias Didácticas, 24(1), 43–58. https://doi.org/10.5565/rev/ensciencias.3813

Gabel, D. L., & Bunce, D. M. (1994). Research on problem solving: Chemistry. Handbook of research on science teaching and learning. MacMillan Publishing Company. pp. 302-326.

García Sepúlveda, S. (2010). Let's learn the concept of substance quantity (Spanish). Revista Digital Innovación y Experiencias Educativas, 27, 1-8.

Gil, D., Carrascosa, J., Furió, C., & Martínez Torregrosa, J. (1991). Science teaching in secondary education (Spanish). ICE-Horsori.

Gulacar, O., Milkey, A., & Eilks, I. (2020). Exploring Cluster Changes in Students' Knowledge Structures Throughout General Chemistry. Eurasia Journal of Mathematics, Science and Technology Education, 16(6). https://doi.org/10.29333/ejmste/7860

Hanson, R. (2019). The Impact of Two-tier Instruments on Undergraduate Chemistry Teacher Trainees: An Illuminative Assessment. International Journal for Infonomics, 12(4), 1920–1928. https://doi.org/10.20533/iji.1742.4712.2019.0198

Huey Chong, S., Goolamally, N., & Eu Leong, K. (2019). Post-secondary Science Students' Understanding on Mole Concept and Solution Concentration. Universal Journal of Educational Research, 7(4), 986–1000. https://doi.org/10.13189/ujer.2019.070410

Kolb, D. (1978). The mole. Journal of Chemical Education, 55(11), 728. https://doi.org/10.1021/ed055p728

Krishnan, S. R., & Howe, A. C. (1994). The Mole Concept: Developing an Instrument to Assess Conceptual Understanding. Journal of Chemical Education, 71(8), 653. https://doi.org/10.1021/ed071p653

Mazzitelli, C. (2013). Prospective teachers and their representations of science education (Spanish). Avances en Ciencias e Ingeniería, 4(2), 99-110.

Merino de la Fuente, M. (2002). The Crisis of Physics: A Chronicle of the European Science and Technology Week 2000 (Spanish). Enseñanza de las Ciencias, 20(1), 185-190.

Millar, R. (1989). Constructive criticisms. International Journal of Science Education, 11, 587-596. https://doi.org/10.1080/0950069890110510

Mol-BIPM. (2023). Available online: https://www.bipm.org/en/history-si/mole (accessed on 4 May 2024).

Moss, K., & Pabari, A. (2010). The mole misunderstood. New Directions, 6, 77–86. https://doi.org/10.11120/ndir.2010.00060077

Núñez, J. C., & González-Pumariega, S. (1996). Motivation and school learning (Spanish). En Congreso Nacional sobre Motivación e Instrucción.

Pozo, J. I. (1993). Learning strategies (Spanish). In: En Desarrollo psicológico y educación II. Alianza. pp. 235-258.

Pozo, J. I., & Gómez Crespo, M. A. (1998). Learning and teaching science (Spanish). Morata.

Paoloni, L. (1981). Chemistry as Part of Culture: a Challenge to Chemical Education. European Journal of Science Education, 3(2), 139–144. https://doi.org/10.1080/0140528810030204

Quijano Cedeño, A. A., & Navarrete Pita, Y. (2022). Chemistry teaching: the need for reinforcement and understanding in high school students (Spanish). Revista Oratores, 13–23. https://doi.org/10.37594/oratores.n15.603

Ratto, J. (2012). Dissertation: Science Education (Spanish). Academia Nacional de Educación (Argentina). Available online: http://www.acaedu.edu.ar/index.php?option=com_content&view=article&id (accessed on 3 March 2015).

Reboiras, M. D. (2006). Chemistry, the basic science (Spanish). Thomson.

Rosado, L., & Herreros, J. (2009). New didactic contributions of virtual and remote laboratories in physics teaching (Spanish). En

Recent Research Developments in Learning Technologies, International Conference on Multimedia and ICT in Education, 22-24.
Schmidt, H. (1994). Stoichiometric problem solving in high school chemistry. International Journal of Science Education, 16(2), 191–200. https://doi.org/10.1080/0950069940160207
Staver, J. R., & Lumpe, A. T. (1995). Two investigations of students' understanding of the mole concept and its use in problem solving. Journal of Research in Science Teaching, 32(2), 177-193. https://doi.org/10.1002/tea.3660320208
Vorsah, R. E., & Adu-Gyamfi, K. (2021). High School chemistry teachers' perspectives and practices on teaching mole concept. European Journal of Education Studies, 8(2).
Vygotsky, L. S. (1978). Mind in society: The development of higher psychological processes. Harvard University Press.