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LEARNING SCIENTIFIC REPRESENTATIONS IN THE CONTEXT OF ORGANIC CHEMISTRY

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Abstract

The objective of this article was to design a theoretical model to explain the learning of scientific representations in students of organic chemistry. Methodologically, the study was framed within the positivist paradigm and employed a quantitative approach with a descriptive, non-experimental, cross-sectional, and field design. The population consisted of 50 students. The results revealed that students experienced difficulties in achieving meaningful learning of scientific representations in the context of organic chemistry. Consequently, a theoretical model was developed to foster substantive dialogue connected with real-world contexts, thereby promoting a deeper level of knowledge acquisition. The study concluded by emphasizing the importance of implementing innovative educational models that enhance the understanding of scientific representations in organic chemistry.

Keywords: learning, mental representation, science, knowledge, thinking.

1. Introduction

Organic Chemistry students at the Universidad Popular del Cesar exhibit a noticeable gap in their understanding of scientific representations. This deficiency is largely due to the limited availability of fundamental information on the subject, particularly within the field of chemistry. The primary function of scientific representations is subrogative, or homological, reasoning, which enables the transfer of inferences and results obtained in the representing domain to properties and relationships identified in the represented domain [1].

Moreover, when chemical systems at the atomic and molecular levels are approached merely as sets of particles subjected to different mechanical frameworks, each chemical reaction tends to be treated as an isolated problem of physics. Such an approach diminishes the possibility of applying general laws that govern families of chemical substances. Consequently, it becomes essential to carefully examine students' preconceptions when addressing a chemistry topic in its full depth.

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1.1. Problem Statement

Today, learning and studying the natural sciences, particularly chemistry, requires careful attention and engagement from participants in the information society, especially those involved in the educational process. This demand reflects a paradigm shift characterized by rapid and, at times, incomprehensible changes, which often generate uncertainty in their acceptance, even though they are intended to improve quality of life.

For this reason, it is necessary to study chemical representations, understood as diverse ways of describing everyday phenomena. There is no single absolute truth, but rather a variety of representations. Reality is intrinsically linked to causality and to our ability to interpret the world, beginning with the recognition of indivisible particles such as atoms. In this regard, the language of chemistry is arguably one of the most socially influential symbolic systems in science. Today, even individuals with only a basic education without being professional scientists can recognize symbolic systems used in chemical formulas, associating them with the language of chemistry despite lacking a deep understanding of them. However, interpreting these symbolic notations often makes it difficult to determine the precise name or representation of a given substance [2].

Accordingly, this article examines the presentation of the philosophy of science, considering its relationship with knowledge, structure, and implications within the field of education. Since representation is defined as a constructive process influenced by epistemological and methodological perspectives, it is recommended to approach it from a scientific standpoint. For this purpose, examples of representational constructions in chemistry are discussed.

Similarly, Treagust et al. [3], argue that chemistry teachers use multiple types of representations to explain molecular structures—for instance, spiral models, ball-and-stick models, and others to describe bonds. However, students do not interpret these representations in the same way. As the authors suggest, this occurs because students often view each new representation as additional knowledge to memorize, rather than as a tool that explains previously acquired knowledge. Consequently, such practices influence students' attitudes, which are reflected in classroom activities. Clarifying these representations may constitute a first step toward shaping and promoting changes in students' attitudes and their understanding of chemical symbolism.

From this perspective, it is essential for students to recognize concepts and skills that are particularly relevant to their comprehension, to remain attentive in class, and to seek out unfamiliar terms or symbols in order to understand their meaning. This process is crucial for identifying chemical substances or recognizing transformations within them. Moreover, students are confronted with the inherently abstract nature of chemistry: first, because the discipline employs a symbolic language based on formulas and equations; and second, because it relies on the behavior of atoms, particles, and molecules entities so small that they cannot be directly observed. Therefore, chemical symbols are indispensable for representing elements, molecules, and compounds.

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In organic chemistry, representational methods are particularly prominent in the analysis of reactions. This is because reaction mechanisms and the factors influencing them are central to the discipline. In this context, the concept of representation, understood as reasoning based on symbolic constructs, aligns well with the use of chemical formulas. Representations thus function as reasoning tools to analyze the relationships between elements and their contributions to molecular structures.

Nevertheless, students' persistent lack of knowledge regarding representational methods in chemistry is evident. This gap stems largely from insufficient foundational information about the natural sciences, and particularly about chemical representations. As Ibarra and Mormann [1], emphasize, the central purpose of scientific representations lies in subrogative, or homological, reasoning, which enables the transfer of conclusions and results obtained in the representational domain to the properties and relationships identified in the represented domain.

Galagovsky (2005, as cited in Reyes et al. [4]) further documented that, despite ongoing efforts by the educational community to improve chemistry instruction, students are often unable to fully assimilate the knowledge provided in classrooms and laboratories. From the perspective of higher education teaching practice, persistent challenges in learning and content acquisition have been observed. These challenges arise from multiple factors, such as: difficulties in designing courses at the appropriate level due to educational disparities between students and teachers; the reluctance of instructors to adopt innovative teaching tools; and, finally, science curricula that fail to meet students' needs, interests, and aspirations.

In addition, when chemical systems are reduced to sets of particles at the atomic and molecular levels, subject to mechanistic approaches, each chemical reaction is treated as a unique physical problem. This approach prevents the application of more general laws to groups of chemical substances. Therefore, it is crucial to carefully examine students' preconceptions in chemistry courses when approaching the subject from a comprehensive perspective.

Based on the aforementioned considerations, and with the goal of strengthening teaching and learning processes, this study aimed to design a theoretical model that promotes the learning of representations used in organic chemistry among undergraduate students in Natural Sciences and Environmental Education.

1.2. Sustentos teóricos

1.2.1. Previous Studies

It is of great importance to review the behavior of variables in different contexts by examining studies that preceded this research. At the international level, Canac and Kermen [5], conducted a study titled *Designing an Educational Resource to Introduce Chemical Formulas in Secondary Education* at the University of Paris-Est Créteil. Their research sought to develop didactic material for introducing chemical formulas in secondary education through the lens of the history of French science. The classification of their findings was framed within the theoretical context of didactic reconstruction of teaching–learning cycles and the analysis of

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teaching practices. The initial implementation with some students and teachers revealed that model records, reality, and linguistic references must be anchored at both macroscopic and microscopic levels in order to effectively learn concepts of chemical change and reaction. The first part of the developed resources was implemented in classrooms, emphasizing the importance of learning chemical formulas and highlighting that the use of strategies and didactic resources is fundamental for understanding chemical formulas and symbols.

In Latin America, Ruiz [6], carried out a study titled *Augmented Reality and Learning in Organic Chemistry* at the University of Guadalajara, Mexico. The study proposed the use of augmented reality (AR) as an innovative tool for teaching and learning organic chemistry, representing both a pedagogical innovation and an educational opportunity. The objective was to evaluate secondary school students' learning of organic chemistry supported by AR. Employing a mixed-methods approach, the study used a rubric as the main tool to evaluate AR projects designed with the HP Reveal® application, alongside quizzes to assess student learning. Results indicated an average score of 8.3/10 for AR projects and an average of 7.94/10 on quizzes. The study concluded that AR projects enhance learning conditions in chemistry, particularly in the recognition of formulas and the nomenclature of organic compounds. The article also underscored the importance of AR in achieving meaningful learning, highlighting its role as an information and communication technology (ICT) tool in the teaching and learning of organic chemistry.

At the national level, Herrera [7], conducted a study at Universidad Regional Francisco José de Caldas (Colombia), titled *Didactic Strategy for the Contextual Teaching of the Concept of Isomerism and Structural Organic Chemistry from a Historical, Philosophical, and Epistemological Perspective: A Change in Perspective for Chemistry Graduates*. The study addressed the need to implement didactic strategies in teacher education. Its purpose was to design and implement a didactic strategy that promoted awareness of the history and epistemology of science in knowledge, competence, and teaching practices. The outcome was a contextualized didactic unit demonstrating innovative educational processes, integrating the essence of science into teaching and learning.

The qualitative methodology was based on a case study. Changes in the perspectives of two chemistry teachers were documented through phenomenological study and participant observation across three stages of the proposed strategy. Results indicated that incorporating history and epistemology as integral aspects of teaching provoked significant changes in the teachers' perspectives. Furthermore, the prominence of epistemology demonstrated that the development of epistemological perspectives and critical thinking requires continuous integration of reflective practices, lifelong learning, problem-solving skills, and strategies to overcome learning difficulties.

1.2.2. Philosophical and Epistemological Foundations

Addressing the philosophical and epistemological foundations of learning scientific representations in the context of organic chemistry requires assigning a central role to the philosophy of science. However, not all representational concepts fully meet this expectation

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[8]. Representation as reflection is characterized by the idea that what is represented and the representation itself are essentially the same so much so that one becomes a mirror of the other.

According to Fuentes (2012, as cited in Izaguirre et al., [8]), philosophical and epistemological foundations have gained renewed significance in the context of 21st-century organic chemistry, particularly in learning scientific representations. These foundations are associated with higher-order knowledge generation, information processing, and the communication of symbols, signs, and codes that define educational processes. Such processes cannot be achieved without the cultural re-signification of human beings in their social contexts. The authors found that the philosophical and epistemological underpinnings of learning strengthen knowledge acquisition, enhance meaning-making processes, and facilitate communication in the contexts where learning develops.

1.2.3. Scientific Representations

The concept of representation has been the subject of diverse philosophical positions for decades. Rorty [9] and other neopragmatists argue that the concept inevitably leads to dead ends and pseudo-problems. Nonetheless, it is proposed that representation should hold a central role in philosophy, and particularly in the philosophy of science. Not all notions of representation, however, are adequate to fulfill this role. For example, Rorty [9] claimed that representation understood as reflection is unhelpful, equating it to an image in a mirror (p. 12). In this view, what is represented and the representation are nearly identical one is a reflection of the other.

Based on Rorty's [9], rerspective, such representations have little relevance in science or philosophy. A special case is mathematical representation as isomorphism, which carries minimal significance. In contrast, a truly existing representation observable in scientific practice is a complex and demanding concept that requires theoretical specification. Thus, a theory of scientific representations is necessary.

This introduces a more comprehensive concept of representation, one that more effectively describes the essential properties of scientific representations than those previously proposed. This concept, referred to as homological or functional representation, emerges from the recognition that representation can function as a generalization that has been realized in application [10].

The primary purpose of scientific representations is subrogative, or homological, reasoning, which allows for the transfer of conclusions and results obtained in the representational domain to the properties and connections identified in the represented domain [1]. According to Izquierdo et al. (1999, as cited in Reyes et al. [4]), significant difficulties persist in science education. One of the main objectives of changing teaching strategies is to enable students to construct their own knowledge, recognize their errors, and engage in self-regulation. To achieve this, teachers must conduct preliminary inquiries that reveal students' prior knowledge and alternative conceptions [11].

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Additionally, since the representational domain is structurally richer than the represented domain, subrogative reasoning can leverage theories formulated in the representational domain and apply them to the represented domain. Therefore, the theory of scientific representations must account for this essential goal of representational practice. This study was developed with the intention of contributing to the construction of such a theory [1].

1.2.4. Teaching Organic Chemistry

According to Gillespie [12], the central ideas of chemistry are: atoms, molecules, and ions; chemical bonding; molecular formulas and geometry; kinetic theory; chemical reactions; energy; and entropy. Among these, the author identifies the chemical reaction as the most important idea, as it provides the explanatory basis for chemical phenomena. Understanding this concept makes it possible to organize transformations of matter and to comprehend how certain substances transform into others. The concept of a chemical reaction, defined as "the process by which chemical species are transformed" (IUPAC, 2006, as cited in Reyes et al [4].), is therefore fundamental for chemistry teachers and is consistently included in curricula.

Caamaño and Oñorbe [13], argue that understanding chemical reactions is a key part of the conceptual framework of chemistry. However, Kind [14], points out that in conventional teaching, students often retain alternative conceptions of chemical reactions that are not effectively addressed. Moreover, it has been observed that most textbooks and teachers devote limited space and time to explaining these conceptual aspects.

McMurry [15], emphasizes that chemistry is a unified science, governed by the same principles that explain the behavior of all substances regardless of their origin or complexity. The distinguishing feature of organic compounds is simply that they all contain the element carbon. According to Pastré [16], the activity of a learner whether student or teacher encompasses two dimensions: productive activity, which corresponds to the completion of a task (the subject acts upon something real), and constructive activity, which involves the cognitive effects resulting from the completion of tasks (real changes in understanding or practice).

Depending on the nature of the tasks, constructive activity may vary in importance, ultimately leading to the reorganization of cognitive structures. This reorganization underlies both students' concept formation and teachers' professional development. Within this framework, teaching practices are shaped by the responses (preparation and delivery of lessons) that a teacher provides to formal instructional guidelines, while considering the limitations imposed by their resources and working conditions [17].

1.2.5. Learning Strategies

Learning strategies are defined as "actions or mental operations used to facilitate the acquisition of knowledge containing a plan of action with mechanisms that learners may employ in the learning process" [4]. Similarly, Monereo (2000, as cited in Vásquez [18]) defines them as "a set of activities carried out to achieve a learning goal" (p. 27).

Galperin (as cited in Vásquez, [18]) emphasizes the importance of directing the learning process, noting that it is essential to select and organize activities to ensure the development of

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knowledge and skills with the required quality. Meza and Lazarte (2007, as cited in Reyes [4]) further define learning strategies as "internally organized skills that individuals use to regulate their affective and cognitive processes in order to achieve goals; they contain plans that are implemented through activities, techniques, and procedures" (p. 22).

Collectively, these perspectives highlight that learning strategies provide opportunities to motivate learners, support the acquisition of new knowledge, and strengthen both cognitive and affective processes through diverse activities.

2. Materials and methods

The positivist paradigm was selected for this study, which investigated scientific representations in the context of organic chemistry. The research was based on a quantitative approach, as it "relies on the collection of data to test hypotheses, behavioral models, and theories based on numerical measurements and statistical analysis" [19]-[20]. The study employed a non-experimental, cross-sectional, and field design, in which the social situation was incorporated to improve the quality of activity within it. In this sense, the study sought to confirm the theory underlying applied education, not independently, but through educational practice [21]. (Elliot, 2000).

The research was framed within a field design, as it was conducted in the actual setting of the object of study. According to Arias [22], this design involves collecting data directly from reality, where events occur, without manipulating or controlling any variable.

Additionally, the study adopted a longitudinal perspective, as the variable under investigation was observed in its natural context at two different points in time. The instrument was administered twice to the same sample in order to gather the necessary data. As Méndez [23] explains, longitudinal studies are designed by "measuring a variable or set of variables at least twice to assess their development."

The data collection techniques and instruments included two questionnaires. The first was a dichotomous scale with Yes–No response options. The second consisted of self-administered structured questions, applied to students using a five-point Likert scale (5–1), with the following response options: Strongly Agree (SA), Moderately Agree (MA), Neither Agree nor Disagree (NAND), Moderately Disagree (MD), and Strongly Disagree (SD).

For the analysis of results, a scoring scale was used with a maximum of 33 points for each dimension. Interpretation of the scores was based on the overall results of all participants. The primary criterion for interpretation was the proportionality of points obtained in each dimension. The results were classified into five levels, following the procedure suggested by Useche et al [24].

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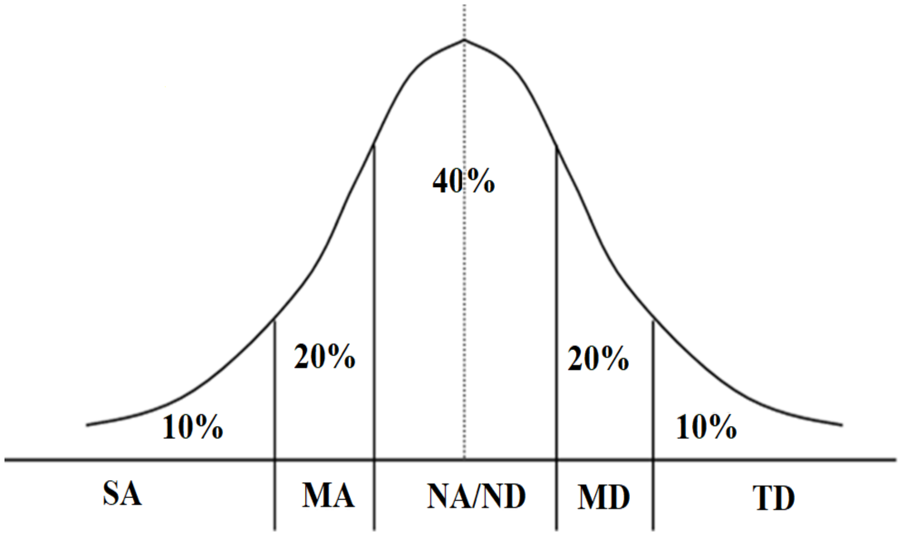
Figure 1. *Results of the rating scale.*



Note. The figure illustrates respondents' tendencies in expressing their opinions, using the criteria Strongly Agree (SA), Moderately Agree (MA), Neither Agree nor Disagree (NAND), Moderately Disagree (MD), and Strongly Disagree (SD). Emphasis is placed on the criterion *Neither Agree nor Disagree*.

The study population was located in the university context of the Universidad Popular del Cesar, in the municipality of Valledupar, Department of Cesar, Colombia. It consisted of 50 undergraduate students enrolled in the Bachelor's program in Natural Sciences, who were taking the Organic Chemistry course during their fourth semester.

3. Results and Discussion

To develop a theoretical model explaining students' learning of scientific representations in the Organic Chemistry course of the Bachelor's program in Natural Sciences and Environmental Education at Universidad Popular del Cesar, it was necessary to measure the variable *forms of scientific representations in natural sciences*. This variable comprised four dimensions: philosophical and epistemological foundations, scientific biases, thinking styles, and learning strategies. For each dimension, measures of central tendency were calculated to analyze the behavior of the variable.

Within the Philosophical and Epistemological Foundations dimension, two sub-dimensions were considered: *Practice of Organic Chemistry* and *Symbolism of Organic Chemistry*. The results obtained for this dimension are presented below:

Table 1.*for the dimension Philosophical and Epistemological Foundations*

Dimensión	Sub-dimension	Yes %	No %	Conclusión
	Praxis of Organic Chemistry	86%	14%	The trend indicates prior knowledge

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Dimensión	Sub-dimension	Yes %	No %	Conclusión
Philosophical and Epistemological Foundations	Symbolism in Organic Chemistry	80%	20%	The trend indicates prior knowledge
Mean		**83%**	**17%**	
Average Score		**4,15%**	**0,17%**	**4,32**

Note. The table reports the percentage of responses from the study sample, indicating that students acknowledged knowledge of the praxis and symbolism of organic chemistry. This finding is further supported by the average score.

In the dimension of Philosophical and Epistemological Foundations, it can be concluded that 83% of the students demonstrated knowledge of this area. Furthermore, the score obtained for this dimension was 4.32, which, according to the evaluation scale, indicates a high level of knowledge (HK) regarding philosophical and epistemological foundations.

Within the sub-dimensions, *Praxis of Organic Chemistry* revealed that 86% of the students showed proficiency in applying organic chemistry practices, while *Symbolism in Organic Chemistry* showed that 80% were able to manage the symbols commonly used to work with reactions and mechanisms in the subject. The results of this dimension highlight the importance of representations and their study from the perspective of the philosophy of science, since representation is defined as a constructive process grounded in epistemological and methodological implications. In this sense, this research emphasizes the relevance of examining science and the representations employed in organic chemistry.

Table 2. *Representations of Science*

Variable	Dimension	average score	Conclusion
Representations of Science	Philosophical and Epistemological Foundations	4.32	High knowledge (HK) of the philosophical and epistemological foundations
	Scientific Preconceptions	4.4	The tendency is to be moderately in agreement (MA)

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Variable	Dimension	average score	Conclusion
	Thinking Styles	4.1	The tendency is to be moderately in agreement (MA)
	Learning Strategies	4.18	The tendency is to be moderately in agreement (MA)
Overall Average Score		4.25	
Variance		0.018	
Standard Deviation		0.1351	

Note. The different dimensions of scientific representations indicate a moderate agreement regarding the importance of preconceptions, thinking styles, and learning strategies for understanding organic chemistry, despite the students' high level of knowledge of the philosophical and epistemological foundations of science.

The calculated statistics indicated that the average score for the variable was 4.25, a value that falls within the confidence interval [4.11, 4.38], which depends on the calculated standard deviation. The central tendency suggests that students are moderately in agreement with the preconceptions of science, thinking styles, and learning strategies, while showing a high level of knowledge regarding the philosophical and epistemological foundations.

According to Feria and Zúñiga [25], representation is what can be observed in the effective practice of science. It is a complex and "difficult" concept that requires elaboration and clarification; in other words, it is a concept whose understanding necessitates a theory of scientific representations or a learning model of such representations, which is the central aim of this study.

Philosophical and epistemological foundations

To measure this dimension, two sub-dimensions were considered: *Praxis of Organic Chemistry* and *Symbolism in Organic Chemistry*. The results obtained for this dimension are presented below:

Table 3. Results of the sub-dimension *Praxis of Organic Chemistry*

SUB-DIMENSIÓN	ITEMS	INDICATOR	YES %	NO %	CONCLUSION
	1	Observation	100%	0%	

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SUB-DIMENSIÓN	ITEMS	INDICATOR	YES %	NO %	CONCLUSION
	2		93%	7%	The trend indicates that students possess knowledge
	3		83%	17%	
		Mean	92%	8%	
		Score	4.61	0,08	4.69
	4	Assemblies	97%	3%	The trend indicates that students possess knowledge
	5		83%	17%	
Praxis of Organic Chemistry	6		93%	7%	
		Mean	91%	9%	
		Score	4.56	0.09	4.64
	7	Assemblies	80%	20%	The trend indicates that students possess knowledge
	8		90%	10%	
	9		57%	43%	
		Mean	76%	24%	
		Score	3.78	0.24	4.02
Overall Mean			86%	14%	
Overall Average Score			4.31	0.14	4.45

Nota: Martínez, L. (2013)

The average score obtained in this sub-dimension was 4.45, which, according to the interpretation scale, indicates that the group was *in total agreement*. This result derives from the information collected from students enrolled in the Organic Chemistry course of the Bachelor's Degree in Natural Sciences and Environmental Education at the Universidad Popular del Cesar, based on their responses to the instrument designed to measure knowledge of the praxis of organic chemistry. Specifically, it was observed that for the Observation indicator, 92% of students demonstrated knowledge, with a group score of 4.69; for the Assemblies indicator, 91% showed knowledge, with a score of 4.64; and for the Measurement indicator, 76% showed knowledge, with a score of 4.02.

In this regard, Ibarra and Mormann [1], argue that the purpose of scientific representations is *surrogative or homologous reasoning*, which allows for the transfer of inferences and results obtained in the representing domain to the properties and relationships identified in the represented domain. This becomes evident when students employ their observations and skills to perform the necessary actions when solving a problem in organic chemistry.

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Table 4. Results of the Sub-dimension: Organic Chemistry Symbolism

SUB-DIMENSIÓN	ITEMS	INDICATOR	YES %	NO %	CONCLUSION
Organic Chemistry Symbolism	10	Observation	87%	13%	The trend indicates that students possess knowledge
	11		97%	3%	
	12		80%	20%	
		Mean	88%	12%	
		Score	4,39	0,12	4.51
	13	Assemblies	63%	37%	The trend indicates that students possess knowledge
	14		80%	20%	
	15		63%	37%	
		Mean	69%	31%	
		Score	3,44	0,31	3.76
	16	Assemblies	93%	7%	The trend indicates that students possess knowledge
	17		77%	23%	
	18		77%	23%	
		Mean	82%	18%	
		Score	4,11	0,18	4.29
Overall Mean			80%	20%	
Overall Average Score			3,98	0,20	4.29

Note: Martínez, L. (2013)

In this sub-dimension, it is evident that 80% of students demonstrate knowledge of symbolism in organic chemistry, which is confirmed by the score obtained in this topic (4.19) according to the interpretation scale.

This result derives from the data collected from students enrolled in the *Organic Chemistry* course of the Bachelor's Program in Natural Sciences and Environmental Education at the Universidad Popular del Cesar, when completing the instrument designed to measure knowledge of symbolism in organic chemistry. The analysis revealed that in the indicator *nomenclature*, 88% of students were knowledgeable, obtaining a score of 4.51; regarding the indicator *operators*, 69% showed knowledge, with a score of 3.76; and in the indicator *equations*, 82% demonstrated knowledge, obtaining a score of 4.29.

For this reason, Sánchez. and Sánchez [2], argue that the language of chemistry is possibly one of the most socially influential symbolic systems of science. Consequently, any moderately informed person, not necessarily a scientist, can recognize certain symbolic systems used in

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chemical formulas. This is even more so in the case of natural science students, who readily associate certain formulas with the specific language of chemistry.

Table 5. Results of the Dimension Philosophical and Epistemological Foundations

DIMENSION	SUB-DIMENSION	YES %	NO %	CONCLUSION
Philosophical and Epistemological Foundations	Praxis of Organic Chemistry	86%	14%	The tendency is that students are knowledgeable
	Symbolism in Organic Chemistry	80%	20%	The tendency is that students are knowledgeable
Mean		83%	17%	
Average Score		4.15	0.17	4.32

Note: Martínez, L. (2013)

From the dimension of Philosophical and Epistemological Foundations, it can be concluded that 83% of students demonstrated knowledge in this area. Moreover, the score obtained for this dimension was 4.32, which, according to the interpretation scale, indicates a high level of knowledge (HK) of the philosophical and epistemological foundations of science.

In the sub-dimension Praxis of Organic Chemistry, 86% of students showed proficiency in praxis, while in the sub-dimension Organic Chemistry Symbolism, 80% demonstrated familiarity with the symbols used to represent reactions and mechanisms in the subject.

Consequently, the results of this dimension underscore the importance of representations and their study from the philosophy of science, as representation is defined as a constructive process based on epistemological and methodological implications. For this reason, this research situates its analysis from the perspective of science and the representations employed in organic chemistry.

Scientific Representations Variable

Based on the results obtained in each of the previously analyzed dimensions, it is possible to assess the overall behavior of the variable *scientific representations*. The calculated statistics are presented in the following table:

Table 6. Results of the Variable Scientific Representations

VARIABLE	DIMENSION	MEAN SCORE	CONCLUSION
Scientific Representations	Philosophical and Epistemological Bases	4.32	High knowledge (HK) of the philosophical and epistemological foundations

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	Scientific Preconceptions	4.4	The trend is to be moderately in agreement (MA)
	Thinking Styles	4.1	The trend is to be moderately in agreement (MA)
	Learning Strategies	4.18	The trend is to be moderately in agreement (MA)
Overall Mean Score		4.25	
Variance		0.018	
Standard Deviation		0.1351	

Nota: Martínez, L. (2013)

It can be observed that the calculated statistics indicate that the mean score of the variable is 4.25, a value that falls within the confidence interval of [4.11, 4.38], which depends on the calculated standard deviation. The trend of the central statistic is to be moderately in agreement with scientific preconceptions, thinking styles, and learning strategies, while there is a high level of knowledge of the philosophical and epistemological foundations.

According to Rorty [9], representation is what can be observed in the effective practice of science; it is a complex and “difficult” concept that requires elaboration and elucidation. In other words, to understand representation, a theory of scientific representations or a model of their learning is necessary, which is precisely the objective of this research.

Theoretical Model for Learning Scientific Representations in Organic Chemistry

A theoretical model was developed based on the biases, thinking styles, and learning strategies of students enrolled in the Natural Sciences and Environmental Education program at the Universidad Popular del Cesar. The processing of organic compounds is a crucial subject because of its significant utility in the synthesis of these compounds. Thus, the model aimed at the integral resolution of problems, which requires understanding each symbol and algorithm used in organic processes, the applicability of concepts that strengthen their foundation for construction, and practical verification directed toward achieving a high level of understanding of the representations used in organic reactions.

For Bachelard [26], all knowledge is an answer to a question; therefore, in any constructivist model of learning, problem-solving is essential for conceptual development. The main feature of problem-solving is to take students’ own thoughts as working hypotheses, including even the most secure and obvious preconceptions. From this perspective, learning scientific representations in organic chemistry as well as learning in all areas of knowledge goes beyond conceptual, procedural, and attitudinal change. Instead, it proposes learning through the resolution of open-ended problem situations that may engage students’ interest.

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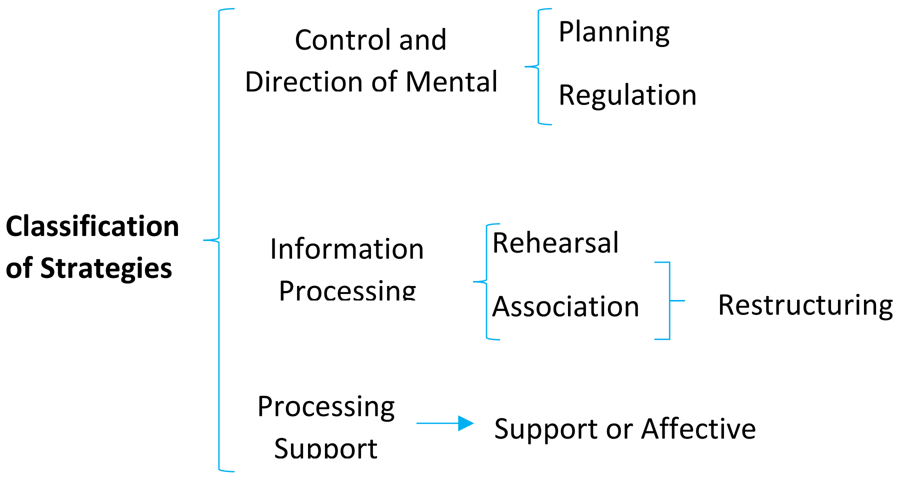
In this sense, the central idea is that the method used in organic chemistry and in any science for learning scientific representations should be consistent with the aforementioned methodology. It should help students modify and/or overcome their prior ideas, allowing them to learn important scientific concepts, procedures, and attitudes. In summary, a problem-solving model applied to scientific representations simultaneously fosters conceptual, procedural, and attitudinal change, where different learning strategies are applied, and procedures are emphasized as metadata when linked to reasoning that enables knowledge.

Theoretical Foundation

According to the cognitive approach, Feria and Zúñiga [25], argue that learning is a process that changes a person's cognitive system, more or less irreversibly increasing subsequent performance in one or more tasks. Newman and Wehlage (1993, as cited in Reyes [27]) note that the strategies guiding authentic learning have the following characteristics: social support for achievement, substantive dialogue, connections to the real world, depth of knowledge, and higher-order thinking.

In the academic context, Pozo (1993, as cited in Herrera, [7]) identified five general types of strategies in the educational domain. The first three help students elaborate and organize content to facilitate learning (information processing); the fourth is aimed at controlling the student's mental activity to direct learning; and finally, the fifth supports learning to ensure that it occurs under the best possible conditions, as illustrated in Figure 1.

Figure 1. *Classification of Learning Strategies.*



Note. The classification of strategies according to the criteria of Pozo (1993, as cited in Herrera, [7]) becomes the fundamental basis for understanding learning and ensuring that it is meaningful. Thus, three main characteristics can be identified: the control and direction of mental activity, which includes planning, regulation, and evaluation; information processing, which encompasses rehearsal and restructuring through association and elaboration; and processing support, provided through effective assistance.

Criteria that Support the Learning Process. To work effectively in teaching, it is necessary to be selective and focus on what is important; this means knowing how to isolate the most

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relevant ideas and understanding what the object or process under study has to offer. If students do not know how to rank ideas according to their importance, they will not only fail in the exercise of attention, but they will also be unable to carry out essential tasks in the study and use of scientific representations, such as underlining, summarizing, or synthesizing [28].

In this sense, non-strategic students and poor readers process information in fragments, which leads to incomplete comprehension because they fail to make connections between main ideas and the representations presented. They cannot form a holistic and general understanding of the text content. Therefore, the key is not only for the teacher to highlight what is important but also to teach students how to recognize it through scientific evidence. Reading is primarily comprehension: good readers differ from poor readers not only by their purpose for reading but also by how they read and how they regulate their own mental activity during reading.

For this purpose, students need to apply reading strategies especially in chemistry where understanding representations and symbolic systems is fundamental to learning. Examples include rereading a passage if it is not understood, reading in different ways to retain the global meaning of the text, and using context instead of ignoring unclear parts. A good student is characterized not only by what they know but also by how they use their knowledge. Synthesizing ideas in writing is one of the best ways to express and present a problem. Memory must be used to process the information received. This information is meant to reach the brain, be processed, and assimilated intelligently in a way that is useful and applicable. To achieve this, the student must practice the subject matter.

Syntax of the Model. Based on the analysis of preconceptions, thinking styles, and learning strategies of undergraduate students in the Natural Sciences and Environmental Education program at the Universidad Popular del Cesar enrolled in the Organic Chemistry course, a common theoretical framework has been identified. This framework can be extended to any type of knowledge that can be problematized, such as the reaction mechanisms of organic compounds.

Evaluation of the Model. The evaluation of the theoretical model for learning forms of scientific representation in organic chemistry takes into account specific competencies in the natural sciences, such as the explanation of phenomena, where students must identify and distinguish phenomena, representations, and related questions. Similarly, inquiry skills are considered, allowing students to formulate questions and relevant procedures, as well as to search, select, organize, and interpret information to answer those questions. Finally, the extensive use of scientific knowledge is emphasized, where students can construct and understand arguments, representations, or models that provide explanations of phenomena.

Based on this, competent evaluation integrates the level of understanding of knowledge, manifested in the achievement of learning goals within a given timeframe, according to each student's abilities and individual differences. Time is needed to reach a well-established level of knowledge, which requires a suitable model that promotes the learning of scientific representations in organic chemistry.

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Other competencies worth considering align with this perspective: interpretative ability, which combines understanding the information presented in an organic chemistry problem—whether expressed through symbols, equations, graphs, or other forms of representation. Likewise, argumentative skills involve explaining and justifying statements, problems, or situations in organic chemistry through the use of evidence, validations, connections, support, applications, and analysis of the original problem. Finally, propositional competence refers to production and creation, observable in activities such as proposing, formulating, generating explanations, or suggesting solutions to a given problem.

Application of the Theoretical Model for Learning Scientific Representations in Organic Chemistry

Below is an example of applying the theoretical model for learning scientific representations in organic chemistry.

- Institution: Universidad Popular del Cesar
- Faculty: Leonardo Enrique Martínez Arredondo & Gustavo Adolfo González Roys
- Level: Undergraduate
- Area: Chemistry
- Semester: IV
- Course: Organic Chemistry
- Topic: Organic Reactions
- Time: 5 hours

General Objective

Apply scientific representations in the resolution of organic reaction problems, identifying the variables, symbols involved, and the relationships among them.

Learning Objectives

- Use scientific representations to solve organic reaction problems.
- Relate each stage of problem-solving in organic chemistry by applying scientific representations.
- Value the contribution of organic chemistry to regional and societal development.

Conceptual and Support Framework

The following aspects will be studied: types of organic reactions, reactions and mechanisms of oxygenated, nitrogenated, cyclic, and aromatic compounds. Supporting materials will include textbooks on organic chemistry, slides, models and simulations on the behavior of organic compounds, chemistry software, computers, video projectors, among others.

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Application

- Presentation of the topic, excluding the specific concepts to be addressed.
- Sharing of general and specific objectives with the students.
- Highlighting the importance of the topic, supported by its historical background and applicability.

Development

- Elicitation of prior ideas or identification of concepts through guiding questions, such as:
  - What do you know about organic reactions?
  - What is a reaction mechanism?
  - How do you determine the type of bond cleavage that occurs in the compounds involved in the reaction?
  - How can you use scientific representations in problem-solving?
  - What is the purpose of the symbols presented in the reaction?
  - What contributions have organic compounds made to science and society?

- Individual work, where each student must respond to the questions posed.
- Sharing of responses and conceptual maturation: In pairs, students exchange their answers, then several responses are discussed collectively. Coincidences and divergences are highlighted, and these are confronted with the course texts to deepen the concepts, verifying and comparing answers with those initially recorded.
- Socialization of new findings or formalization of the concept: Participation of several students, comparison with initial ideas, and teacher's guidance oriented toward reaching a consensual understanding of knowledge.

Practical component

Based on the answers students gave to the posed situation when probing their prior ideas, the teacher focuses the activity by asking them to treat the given response as a hypothesis to solve the situation, and to think about how to verify it. The teacher poses the following verification questions:

- Which variables or unknowns intervene in the situation?
- How can the variables be determined using the materials provided?
- What relationship exists between the variables or unknowns?
- Can this situation be represented in another way?

Proposing an alternative solution and validating the procedure

Based on the previous answers, propose a way to respond to the posed problem and use the textbooks to validate the procedure. Then review the obtained answer and revisit the problem

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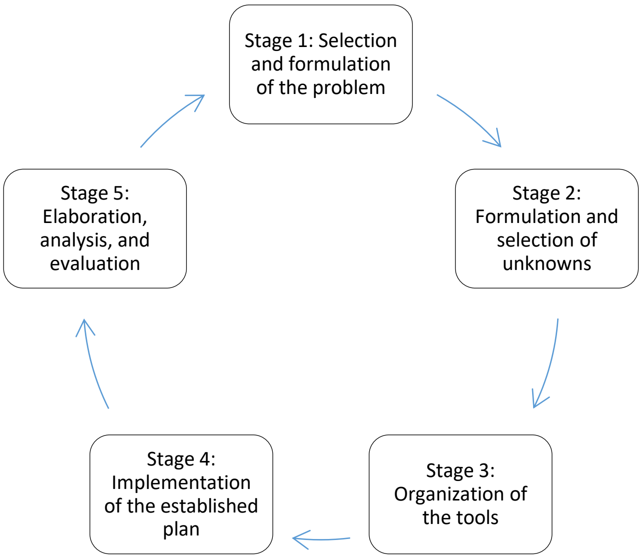
or situation from the beginning to determine whether the stages used in solving the problem are coherent with the procedure and, if necessary, add or remove any step.

Final activity

- Review the details of the problem solution thoroughly and meticulously.
- Consider the solution from several points of view and seek points of contact with your prior knowledge or preconceptions.
- Examine the details of the solution and try to make them as simple as possible; reconsider them more deeply and attempt to simplify them.
- Attempt to modify, for the benefit of the solution, any parts or stages that can be changed so that the objective is achieved, even if the procedure varies in some respects.
- Carefully examine the method you used to reach the solution, endeavour to understand its rationale, and try to apply it to other problems.

Figure 2.

Stages of the model for learning scientific representations in organic chemistry.



Note. Figure 2 summarizes the stages of the model for learning scientific representations in organic chemistry, aimed at fostering comprehension of the learning process and highlighting the importance of organic chemistry in the life of living organisms.

4. **Conclusiones**

The results presented showed that undergraduate students in the Bachelor's program in Natural Sciences and Environmental Education need to develop social and scientific representations of organic chemistry. This revealed the weakness of scientific biases and their philosophical and epistemological foundations. The learning process enabled students to discover their own way of thinking, providing them with maturity and confidence to acquire new knowledge, solve problems, and develop skills.

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This process required the application of learning strategies in which each student designed, regulated, and evaluated the direction of their mental activity, and subsequently processed information through rehearsal, integration, and elaboration. This led to a reorganization that allowed for practical and reliable recognition to achieve meaningful learning by applying techniques aligned with their individual styles. Learning was achieved in a simple, productive, and practical manner, supported by the development of a theoretical model that promoted the learning of representations of organic chemistry among undergraduate students in the Bachelor's program in Natural Sciences and Environmental Education at Universidad Popular del Cesar.

The theories described in the model were adapted to the students' needs to recognize and apply representations of organic chemistry, which received social support through real dialogue and connections with the real world. This fostered a deeper understanding of the knowledge provided by chemistry, guiding them toward a more balanced way of thinking.

The development of the learning design for scientific representations in the context of organic chemistry was carried out in stages, each one built according to the learning needs. It began with the selection and formulation of the task; once the problem was chosen, the next step was to explore unknown options to guide its solution, organize the necessary resources to implement the proposed plan, and finally conduct an evaluation to reinforce student learning.

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