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The construction of scientific explanations in the classroom: an analytical framework based on typological and topological meanings

Abstract

This paper addresses a persistent challenge in science education: students' difficulty in transitioning from macroscopic observations to explanations based on microscopic models. To analyze this problem, the perspectives of typological and topological meanings are adopted. Through a qualitative case study, the behaviour of gases, as understood by secondary school students (13-14 years old), is examined in depth. The main contribution of this research is the development and application of an innovative analytical framework structured in four interrelated dimensions: categorization, relations, temporal, and integration. This framework proves to be a novel and powerful tool for identifying and characterizing the tensions that arise in students' processes of meaning-making. The results reveal that the most critical tension manifests in the temporal dimension, where everyday language, which favours discrete categories, is insufficient to express the continuity of physical processes. These findings have significant implications for teaching practice, suggesting the need to design specific pedagogical scaffolds that make these tensions explicit and help students construct scientific explanations that coherently integrate the different levels of description.

Keywords: school scientific explanations, typological and topological meanings, science education, qualitative research

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Introduction

Scientific explanations are a fundamental element in learning science.[1] Current curricular proposals identify the construction of scientific explanations as an essential practice that students must develop during their training, recognizing that this practice is fundamental for developing scientific thinking and a deep understanding of natural phenomena.[2]

Learning science implies that students take ownership of the scientific community's specific ways of seeing and explaining the natural world, including particular purposes, forms of observation, and methods that support their explanations.[3] Students face various challenges when constructing scientific explanations for schoolchildren since these are not mere descriptions but seek to clarify how and why a particular phenomenon occurs, establishing connections between what is observable and the underlying mechanisms.[4]

Research on constructing scientific explanations for schoolchildren has identified various critical aspects. Kapici[5] documented students' difficulties in integrating different levels of description when explaining physical and chemical phenomena. For their part, Fernandes et al.,[6] have shown that students who manage to develop more sophisticated explanations are those who can establish effective connections between different ways of representing phenomena.

As Lemke[7,8] points out, typological and topological meanings emerge as valuable conceptual tools to analyze how students construct scientific explanations. While typological meanings allow categorizing and classifying phenomenon elements through discrete categories and qualitative oppositions, topological meanings facilitate understanding continuous variations and functional relationships between variables. This distinction is fundamental to understanding how students construct meanings in their scientific explanations.[9] It is particularly relevant since both types complement each other and operate together in constructing school scientific explanations.

This paper aims to develop and apply an analytical framework to examine how students construct school scientific explanations of everyday phenomena from the perspective of typological and topological meanings, identifying the dimensions and tensions that emerge in this process.

This research is justified by the need to understand how students construct scientific explanations in greater depth, particularly the tensions that emerge when integrating different types of meanings. This knowledge is essential for designing more effective teaching strategies that support the development of more sophisticated scientific explanations in the science classroom.

Typological and topological meanings

Typological and topological meanings play a fundamental role in the teaching and learning of science, particularly in physics and chemistry, as several recent studies have shown (Tytler et al., 2020).[7,8] Typological meanings relate to nominal and categorical aspects, allowing phenomena to be classified and described through qualitative oppositions. For example, when students describe temperature as "hot" or "cold," they are utilizing typological resources that, although lacking scientific precision, serve as a starting point for constructing more elaborate meanings (Tang & Tan, 2017). As Mortimer and Scott (2016) point out, these meanings serve as an initial scaffolding, enabling students to begin conceptualizing physical phenomena through their everyday language.

On the other hand, topological meanings represent continuous or almost continuous variations in the properties of natural phenomena, such as temperature, pressure, or speed. These meanings are essential to understanding mathematical relationships and functional dependencies between variables.[8] The importance of topological meanings lies in the fact that they enable us to visualize and understand patterns of change and quantitative relationships that are fundamental to scientific thinking.

An important aspect is that both types of meanings do not operate in isolation but are intertwined in constructing scientific knowledge. Soto[10] argue that physical-mathematical structures, such as F = ma, condense both nominal (typological) and relational (topological) meanings, and the interaction between the two allows for a deep understanding of physical phenomena. This interaction is significant in the educational context, where students must move from qualitative descriptions to more formal mathematical representations.[11]

Proper articulation between the two types of Meaning enables students to develop a deeper and more nuanced understanding of physical and chemical phenomena, facilitating the transition from everyday language to scientific and mathematical language.

Explanations in the science classroom and typological and topological meanings

Scientific explanations in the school context constitute a fundamental element of science learning, differing substantially from everyday explanations and arguments.[12,13] While an argument seeks to establish the validity of a claim through evidence, a scientific explanation aims to account for the causal mechanisms underlying a phenomenon.[13] This distinction is crucial to understanding how students develop their understanding of natural phenomena in the classroom.

The specialized literature has developed various proposals to guide and scaffold the construction of scientific explanations in schools. Among the most relevant is the DEOI (Decision-Explanation-Observation-Inference) method proposed by Van Duzor.[14] This method structures the process of constructing explanations in four sequential stages, allowing students to move from initial observations to more elaborate inferences.

The PRO (Premise-Reasoning-Outcome) scaffold, developed by Tang[15] emphasizes the importance of establishing clear premises and developing explicit reasoning that connects these premises to the observed results. This approach has proven particularly effective in helping students develop more sophisticated explanations that integrate different levels of description.

The PTDR (Phenomenon-Theory-Data-Reasoning) framework, proposed by Yao et al.,[16] provides a structure that helps students connect observed phenomena to relevant scientific theories, using data as a bridge between the two levels. This framework has been instrumental in developing explanations that integrate macroscopic and microscopic aspects.

The Explanation Tool, developed by Braaten et al.,[17] focuses on helping students distinguish between descriptions and causal explanations, emphasizing the importance of identifying the mechanisms underlying observed phenomena. These approaches emphasize providing explicit structures that help students develop more sophisticated explanations, although they differ in their specific approaches and the aspects of the explanatory process they prioritize.

In the school context, scientific explanations are characterized by establishing causal relationships that connect different levels of representation of phenomena. As Valentino et al.,[18] point out, these explanations are not mere descriptions but seek to clarify how and why a particular phenomenon occurs, establishing connections between the observable and the underlying mechanisms. This causal characteristic of school scientific explanations involves articulating typological and topological meanings. Teachers must understand how typological and topological resources collaborate and specialize in constructing scientific meanings. For example, when teaching the concept of acceleration, it is common to start with typological descriptions (“movement gets faster”) and then introduce topological representations through graphs and equations that show the continuous variation of speed over time.

Causal explanations in the science classroom require students to identify and relate relevant variables, establish sequences of events, and understand the interactions between different system components.[19] This process involves progressively constructing increasingly sophisticated representations, where initial typological meanings (qualitative classifications) evolve towards more complex topological understandings (quantitative and functional relationships).

Constructing scientific explanations in the classroom is not a linear or automatic process. As evidenced by Pinnow et al.,[20] students initially tend to propose explanations based on discrete categories (typological meanings), such as “hot/cold” or “fast/slow.” The didactic challenge is to help them develop explanations that gradually incorporate continuous and functional relationships (topological meanings), such as temperature variation as a function of time or acceleration as a rate of speed change.

The role of the teacher as a mediator in this process is fundamental. Teachers must guide the transition from explanations based on discrete categories to those incorporating gradients and continuous relationships. This mediation involves helping students recognize patterns, establish causal connections, and develop explanatory models that integrate typological and topological aspects of the phenomenon.[21]

Teacher mediation in this process must consider three fundamental aspects. First, as Kats et al.[22] point out, it is necessary to create opportunities for students to make their initial explanatory models explicit, which are usually based on typological meanings. Second, experiences must be designed to allow students to recognize the limitations of purely typological explanations and the need to incorporate continuous relationships. Third, it is crucial to provide conceptual and representational tools that facilitate the integration of topological meanings into their explanations.

The construction of school science explanations also requires attention to the social nature of learning. Dragnić-Cindrić et al.[23] have documented how teacher-mediated classroom interactions facilitate the negotiation of meanings and the collective development of explanations. This social process facilitates the transition from explanations based on discrete categories to those that incorporate functional and quantitative relationships.

Integrating typological and topological meanings into school science explanations improves conceptual understanding and develops more sophisticated scientific thinking skills. As Kapici[5] and Fernandes et al.,[6] demonstrate, students who integrate both types of meanings in their explanations show a greater ability to transfer their understanding to new contexts and establish connections between different conceptual domains.

Research context

The study analyses a scientific explanation developed by second-year students (13-14 years old) of secondary education in Buenos Aires, Argentina. The explanation was constructed within the framework of a didactic sequence on the behaviour of gases, which is part of the core content "The corpuscular nature of matter" of the curricular design of the subject Physics Chemistry for the second year of schooling.

This didactic sequence represented the first approach of the group of students to constructing scientific explanations for school, making it a particularly relevant case to analyze the initial processes of meaning construction in the science classroom. The didactic sequence was developed during five consecutive classes, during which the students and the teacher worked on elaborating explanations of everyday phenomena linked to the gaseous state.

The teacher implemented two complementary didactic modalities to guide the process of constructing explanations. In the first modality, she guided the students in elaborating explanations and building them together with them. In the second modality, she guided sharing instances where the students shared their explanations, taking advantage of these moments to model key aspects of constructing scientific explanations in schools.

The explanation selected as a case study for this work corresponds to one developed by the students during this didactic sequence. Its analysis is particularly valuable for two reasons: it represents a first attempt by the students to construct scientific explanations in schools. It allows us to examine how they integrate different meanings when accounting for everyday physical phenomena. The scientific explanation in schools is the following: "As the temperature of the flask increases, the average speed increases, causing the particles to collide against the walls of the flask, stretching it, causing the volume to increase. Moreover, when the temperature of the flask decreases, the average speed decreases, causing the particles to stop colliding, deflating the balloon, that is, decreasing the volume." This explanation constitutes the case of analysis on which the four dimensions proposed to examine the construction of typological and topological meanings in school scientific explanations are applied.

Methodological approach for the analysis of school scientific explanations

This research employs a qualitative approach to analyze how students construct school scientific explanations from the perspectives of typological and topological meanings.[24] The qualitative methodology adopted is particularly suitable for this study because it enables the identification and characterization of the various types of meanings that students mobilize when explaining scientific phenomena, as recent studies in the field of science education have highlighted.[25,26] The research is structured as an instrumental case study, where the detailed analysis of a specific explanation serves as an instrument to understand the broader phenomenon of the tensions between typological and topological thinking.

Research context and case selection

The case under analysis is an explanation developed by a group of second-year secondary school students (aged 13-14 years) in Buenos Aires, Argentina. This explanation was developed during a five-class didactic sequence on the behaviour of gases, representing the students' first formal experience with constructing scientific explanations. The explanation was recorded in writing by the students themselves as the final product of a teacher-guided group discussion.

Of the various productions generated during the sequence, this explanation was selected for analysis because it is a paradigmatic case. It represents, in a prosperous and transparent manner, the initial difficulties and achievements of students as they attempt to connect observations at the macroscopic level (the change in a balloon's volume) with an explanatory model at the microscopic level (the particle model). This makes the theoretical tensions that are the focus of this article explicit.

Analysis procedure

The content analysis of the explanation was carried out through a systematic procedure based on the four-dimensional analytical framework developed in this research. The process was as follows:

I. Segmentation: First, the explanation was broken down into units of Meaning or causal propositions to facilitate coding. For example, the phrase "As the temperature of the flask increases, the average speed increases" was treated as one unit.

II. Dimensional Coding: Next, each unit was examined through the four dimensions:

III. Categorization Analysis: All terms denoting discrete categories (e.g., "temperature," "speed," "particles") and qualitative oppositions (e.g., "increases/decreases," "inflating/deflating") were identified and listed.

IV. Relationship Analysis: Logical and causal connectors (e.g., "causing," "making") were mapped to outline the chain of relationships the students established between the identified variables.

V. Temporal Analysis: The narrative structure of the explanation was examined to determine whether it described the phenomenon as a sequence of discrete states (a "before" and "after") or as a continuous transformation process.

VI. Integration Analysis: Finally, the overall coherence of the explanation was assessed, paying special attention to how students articulated the two levels of description—the observable macroscopic and the underlying microscopic—and integrated typological and topological meanings into a unified whole.

This analytical process allows us to identify patterns and characteristics in the construction of scientific explanations in schools, an aspect highlighted as fundamental in recent research on conceptual development in science.[27]

Dimensions for analysis of explanations

Analyzing school scientific explanations based on typological and topological meanings requires a systematic approach that allows us to understand how students construct meanings when explaining everyday phenomena. This analysis proposal is structured in three fundamental dimensions that interrelate and complement each other.

The first dimension, categorization analysis, focuses on identifying how students use typological meanings to name and classify the elements of the phenomenon they are explaining. Initial categorization is fundamental because it provides the vocabulary and basic conceptual structures on which more elaborate explanations will be built. This dimension reveals how students initially organize their understanding of the phenomenon through discrete categories and specific classifications.[20] For example, when students identify and name elements such as "temperature," "speed," or "particles," they establish the discrete categories that will serve as the basis for building more complex relationships; they establish the conceptual foundations on which they will build their explanations.

The second dimension, relationship analysis, examines how students establish connections between the different variables and concepts they have identified. This dimension identifies the transition from typological to topological meanings.[10] Students begin to establish causal relationships and recognize patterns of covariation between variables, such as when they explain how an increase in temperature is related to an increase in particle speed and the consequent increase in volume.

The third dimension, temporal analysis, examines how students construct the narrative of the phenomenon over time. This dimension allows for recognizing whether students conceive of changes as a sequence of discrete states or a continuous transformation process. The temporal dimension is important because it allows for assessing the understanding of the continuous nature of physical and chemical processes and how students integrate this continuity into their explanations. For example, when describing the evolution of a system over time, they may do so as a series of discrete "snapshots" or as a continuous process of change.

The fourth dimension, integration analysis, assesses how students combine different types of meanings into a coherent explanation, examining the tensions between typological and topological meanings and the ability to connect their explanation to everyday experiences. This dimension examines the tensions between typological and topological meanings, as well as students' ability to connect their explanations to everyday experiences.[28] It reveals how students manage potential contradictions between different ways of understanding the phenomenon and construct an explanation that incorporates both discrete and continuous aspects. For example, when explaining a complex phenomenon, they may need to integrate qualitative descriptions with quantitative relationships or connect macroscopic observations with microscopic models.

These four dimensions are intrinsically related and complement each other, providing a robust analytical framework to examine how students construct scientific explanations in the classroom. Their application allows us to identify achievements and difficulties in constructing scientific explanations, facilitating the design of more effective teaching strategies. Figure 1 presents the dimensions proposed for analyzing school scientific explanations.

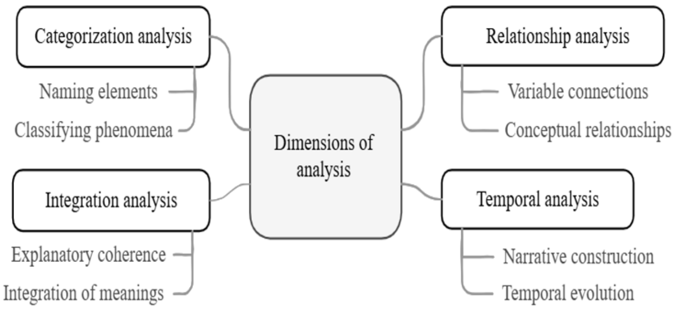

Figure 1 Dimensions for analyzing the content of school scientific explanations of everyday phenomena. Source: own elaboration.

The analysis of school scientific explanations must consider the specific characteristics of each dimension and the tensions that emerge in each of them. These tensions are particularly relevant because they reveal the critical points at which students struggle to transition from a predominantly typological way of thinking to one that incorporates topological aspects.

Results

Analyzing the explanation developed by the students

Dimension of categorization analysis

The categorization analysis of the content of the scientific explanation examines how students use typological meanings to name, classify, and organize the elements of the phenomenon they are explaining. The analyzed explanation identifies several key elements that reveal how students categorize and classify the phenomenon.

First, students identify and name fundamental elements such as "temperature," "average speed," "particles," "shocks," and "volume." They use these discrete and specific categories as a conceptual basis to build their explanation of the phenomenon. This use of discrete categories reflects an initial approach to organizing the understanding of the phenomenon through specific classifications.

Students also employ terms such as "increase" and "decrease" as opposite categories, describing changes between discrete states (high/low temperature, inflated/deflated) rather than describing a continuous variation. This tendency to use opposing categories is evident when describing the balloon as "inflating" or "deflating," which limits their explanation to describing types of states rather than a continuous process.

Causal relationships are set up linearly and discretely, such as "if A increases, then B increases." Students do not show an explicit understanding of how variables vary continuously and simultaneously. Furthermore, they use absolute terms such as "stopping colliding," which suggest a discontinuity in the phenomenon rather than a gradual change in the frequency of collisions.

This form of categorization reveals a tendency to construct scientific explanations from a predominantly typological perspective, favouring discrete categories and classifications over an understanding of continuous processes and dynamic relationships between variables. This feature is significant because it provides the basis for students to develop a more sophisticated understanding, incorporating topological aspects of the phenomenon.

This dimension manifests a fundamental tension between the use of discrete categories and the need to express continuous processes. Students use terms such as "increase/decrease" and "inflate/deflate" as opposing categories when attempting to describe inherently continuous phenomena. This tension is evident when students attempt to use categorical language to describe processes that require understanding continuous variation.

Dimension of relationship analysis: causal relationships and connections in school science explanations

Relationship analysis examines how students establish connections between variables and physical concepts, revealing the transition from typological meanings to more sophisticated topological meanings. This dimension is critical because it allows us to observe how students develop a deeper understanding of causal relationships and patterns of covariation between variables. For example, when they explain how the increase in temperature is related to the increase in particle speed, they establish relationships that go beyond simple categories, incorporating aspects of continuous variation and functional dependence.

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In the analyzed explanation, hints of topological meanings can be identified when students use expressions such as "stretching" and "deflating," which suggest a continuous process of change in the balloon's volume rather than a simple change between discrete states. These expressions, although limited, indicate an incipient recognition of the phenomenon's dynamic nature and the continuous variation of the physical properties involved.

Students also establish causal relationships through expressions such as "causing that," which implies recognizing the connection between different physical variables. However, these relationships are presented linearly and sequentially without showing an explicit understanding of simultaneous covariation between variables. For example, when they describe how increasing temperature affects the speed of particles, which influences the balloon's volume, they establish a causal chain that a deeper understanding of the simultaneous relationships between these variables could enrich.

The absence of terms indicating gradualness, such as "progressively," "gradually," or "as", suggests that students have not yet fully developed topological meanings that allow them to describe continuous variation and functional relationships between the variables involved.

The central tension in this dimension arises between establishing simple causal relationships and understanding complex covariations. Students tend to establish linear connections of the type "if A then B" when physical phenomena involve simultaneous covariation relationships between variables in reality. There is a tension between the tendency to simplify causal relationships and the need to understand complex interactions between variables.

Temporal analysis dimension: temporal dimension in the construction of scientific explanations

Temporal analysis examines how students construct the narrative of the physical-chemical phenomenon over time, revealing their understanding of the processes of change and transformation. This critical dimension enables us to evaluate how students perceive the continuous or discrete nature of physical and chemical processes.

When students construct explanations from a typological perspective, they tend to present events as a sequence of discrete categories, such as "before heating", "during heating", and "after heating". This type of narrative segments the phenomenon into specific moments without providing detailed descriptions of the transitions between them. For example, in the explanation analyzed, students say, "As the temperature of the flask increases..." and then "As the temperature of the flask decreases...", suggesting a clear division between two states of the system without considering the continuous change process.

Causal relationships can also be presented discretely or continuously. Students set up a succession of discrete events from a typological perspective: "The temperature increases, then the particles collide, then the balloon stretches." In contrast, a narrative emphasizing continuity would describe how "as the temperature of the jar gradually increases, the average speed of the particles increases progressively, and the frequency of collisions with the walls of the jar changes continuously."

The temporal dimension also reveals how students understand covariation between variables. A description emphasizing continuity would show how "the average speed of the particles increases in tandem with the temperature, and the balloon stretches continuously with the increase in particle motion." This type of explanation reflects a more sophisticated understanding of the relationships between variables, recognizing their simultaneous and continuous variation.

It is essential to note that everyday language's tendency to rely on discrete categories can make it challenging to express the continuity and covariation of events over time. Therefore, students can benefit from the use of specific linguistic resources such as adverbs and temporal connectors ("gradually", "progressively", "while", "as", "simultaneously") that help express the continuous nature of physical processes.

The temporal dimension of the analysis also allows us to identify how students integrate different levels of description. For example, when they need to connect macroscopic observations (the visible change in the volume of the balloon) with microscopic explanations (the movement of particles), this integration requires a sophisticated understanding of how processes evolve on different time scales and how they relate to each other.

In this dimension, tension emerges between describing discrete events and understanding continuous processes over time. Students tend to segment the phenomenon into specific moments ("before", "during", and "after") as they struggle to express the continuous nature of physical changes. This tension is evident in the use of temporal connectors that suggest discontinuity versus the need to express temporal continuity.

Integration analysis dimension: Integration of typological and topological meanings in scientific explanations

The integration analysis examines how students combine different meanings to construct a coherent scientific explanation of the phenomenon studied. This dimension is particularly revealing because it allows us to observe the tensions that emerge when students try to articulate typological and topological meanings and their ability to integrate discrete and continuous aspects into a unified explanation.

In the explanation analyzed, students try to integrate a macroscopic description of the phenomenon (the visible change in the volume of the balloon) with a microscopic explanation based on the particle model. This integration is evident when they connect the behaviour of the particles ("making the particles hit the walls of the balloon") with the observable macroscopic effects ("stretching the balloon, making the volume increase"). However, this integration shows significant tensions between the need to categorize discrete elements and the description of continuous processes.

The fundamental tension in this dimension is between fragmented understanding and the need for an integrated view of the phenomenon. Students are challenged to integrate their macroscopic observations (what they can see) with microscopic explanations (the particle model). There is also a tension between everyday language, which tends to favour discrete descriptions, and the need to express continuous and complex relationships typical of scientific language.

The explanation also shows a tension between the need to establish discrete categories to organize their understanding (typological meanings) and the implicit recognition of the continuous nature of physical processes (topological meanings). This tension is particularly evident in the simultaneous use of discrete terms, such as "increase/decrease," alongside expressions that suggest continuity, like "stretching" and "deflating."

The integration analysis reveals how students combine different meanings and the difficulties and challenges they face in constructing a coherent scientific explanation that incorporates both discrete and

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continuous aspects of the studied phenomenon. Identifying these tensions provides valuable information for designing teaching strategies that help students develop more sophisticated explanations that effectively integrate both meanings. Figure 2 presents a summary of the results for each dimension of the analysis.

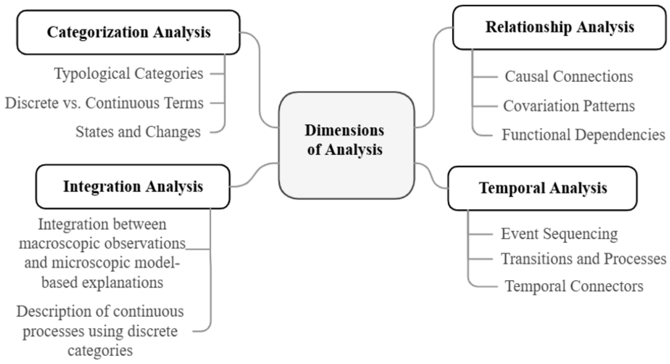

Figure 2 Dimensions of analysis and main findings are identified in the explanation prepared by the students—source: own elaboration.

Discussion of the results

The results of the analysis of the school's scientific explanation, discussed from the perspective of typological and topological meanings, reveal fundamental aspects of how students construct meanings when explaining physical phenomena.

The dimensions of analysis and their tensions reveal that students predominantly employ typological meanings at the beginning of their explanations, categorizing elements and establishing simple causal relationships. This trend aligns with observations made by Soto & Bueno,[10] who noted that students typically begin with discrete categories before developing more sophisticated understandings. However, our analysis reveals that the tensions between typological and topological meanings are more complex than previously documented, particularly in the temporal dimension of the explanations, where students try to express the continuity of physical processes using a language that favours discrete categories.

The results of this work show that these tensions emerge dynamically when students try to explain phenomena that involve temporal changes. This complexity is particularly evident when students attempt to connect discrete descriptions with continuous processes, such as when explaining how particle speed changes with temperature.[29]

Meaning-making emerges as a dynamic process in which students attempt to bridge the gap between discrete descriptions and continuous processes. Reigosa[30] point out that this integration is fundamental to developing a deeper understanding of physical phenomena. The present research results extend this understanding by demonstrating how students attempt to bridge discrete categories and continuous relationships, especially when explaining phenomena involving temporal changes. The analysis reveals that this process is not linear, but rather involves multiple levels of integration between typological and topological meanings.[10]

Regarding didactic implications, as Maton and Doran[29] suggested, identifying tensions between typological and topological meanings provides valuable information for designing didactic strategies. The analysis of student-generated explanations contributes to the field by proposing a more detailed framework for examining these tensions. It suggests the need to develop teaching interventions that explicitly facilitate the transition between meanings. This involves designing teaching strategies that help students recognize and manage tensions between typological and topological meanings.[21]

The "integration analysis" dimension reveals a fundamental tension between macroscopic and microscopic descriptive levels in explanations of school science. In the explanation analyzed, students try to connect what they can directly observe (macroscopic changes in the volume of the balloon) with an explanation based on the microscopic behaviour of the particles. This tension is particularly evident when they try to link the continuous and collective motion of the particles with macroscopic changes such as "inflating" and "deflating" the balloon.[31] The difficulty lies in the fact that students must integrate two levels of description that operate with different logics: the macroscopic level, accessible through direct experience and described mainly by discrete categories (inflating/deflating), and the microscopic level, which requires a model of particles in continuous motion.[5]

This tension is manifested in the language used, where students alternate between discrete descriptions ("when the temperature decreases") and expressions that try to capture the continuous nature of the process ("stretching", "deflating"). The integration between these levels requires students to establish connections between the collective behaviour of particles and observable macroscopic effects. This tension between levels is particularly relevant because it reveals students' challenges in building coherent scientific explanations that integrate different scales of observation and analysis.[28] Identifying this tension provides valuable information for developing teaching strategies that help students construct more sophisticated explanations, effectively integrating both levels of description. This approach recognizes the continuous nature of microscopic processes and their observable macroscopic manifestations.

The present research engages with various proposals designed to inform the construction of scientific explanations in schools. While the DEOI method[14] structures the process in sequential stages that allow students to move from initial observations to more elaborate inferences, and the PRO scaffold[15] emphasizes the importance of establishing clear premises and developing explicit reasoning, our proposal focuses on identifying and characterizing the tensions that emerge when students try to integrate different types of meanings when explaining physical phenomena.

The PTDR framework[16] provides a structure that helps students connect observed phenomena to relevant scientific theories, using data to bridge both levels. In a complementary way, our analysis reveals that the tensions between typological and topological meanings are more complex than previously documented, particularly in the temporal dimension of explanations. While the Explanation Tool[17] focuses on helping students distinguish between descriptions and causal explanations, our work contributes by identifying how students attempt to bridge between discrete categories and continuous relationships.

Our proposal's distinctive contribution lies in providing an analytical framework that allows examining not only the content of explanations but also the tensions that emerge in their construction, especially in the integration between macroscopic and microscopic levels.[28] This approach complements existing proposals by providing specific tools to identify and characterize students' challenges when constructing scientific explanations that effectively integrate different meanings.

In terms of scope and limitations, the proposed analytical framework may be suitable for examining verbal and written explanations in the classroom, which constitute the privileged forms of meaning construction in secondary education science classrooms. The proposal could be extended to analysing how teachers discursively guide the construction of explanations during exchanges with students, considering the fundamental role of teacher talk as a mediator in the learning process.[32] This aspect is particularly relevant, considering the fundamental role of teacher talk as a mediator in learning to construct scientific explanations,[25] and would allow for a better understanding of how teachers can support the transition between typological and topological meanings in classroom interactions.

The pedagogical implications of these findings suggest that it is not enough to point out students' difficulties; it is necessary to design explicit pedagogical scaffolds to support them. Based on the identified tensions, concrete classroom strategies can be proposed. For example, to address the **tension in the temporal dimension** (discrete description vs. continuous process), the teacher could propose activities such as:

I. Linguistic Scaffolding: Provide students with a process-oriented vocabulary, including terms like "gradually," "progressively," "as," or "simultaneously," and ask them to rewrite their initial explanations by incorporating these words to express the continuity of the phenomenon.

II. Creation of a "Storyboard" or Simple Animation: Ask students to represent the explanation not as two states (beginning/end), but as a sequence of vignettes or frames that show the intermediate moments of the process. This task forces them to think about the continuous transition between states.

For the tension in the integration dimension (macroscopic vs. microscopic), strategies could be implemented, such as:

I. Two-Column Explanation: Students could work on a table with two columns. In the first, "What I Observe (Macro)," they describe the visible changes (the balloon inflates). In the second, "What is Happening (Micro)," they draw or describe the particle behaviour that causes that observation. The final goal is to write a paragraph that explicitly connects both columns, building a coherent bridge between the two levels.

II. These strategies do not aim to provide a correct answer but to make the tensions inherent in language and scientific models visible, equipping students with the conceptual and linguistic tools to construct more sophisticated and precise explanations.

Final considerations

Analyzing school scientific explanations from the perspective of typological and topological meanings reveals fundamental aspects of how students construct meanings when explaining physical and chemical phenomena. The four proposed dimensions—categorisation, relationships, temporal, and integration—provide a robust framework for examining the construction of scientific explanations in the classroom, allowing us to identify the achievements and difficulties students face in this process.[33]

Identifying specific tensions between typological and topological meanings in each dimension contributes to understanding how students develop scientific explanations. As Campos et al.,[34] point out, these tensions reveal the critical points at which students seek to transition from descriptions based on discrete categories to explanations that incorporate continuous aspects of physical phenomena. Students move between these types of meanings and try to construct explanations that integrate both perspectives, especially when addressing phenomena involving continuous temporal changes.[35]

This work's original contribution lies in developing an innovative analytical framework that enables us to identify and characterise the tensions that emerge when students attempt to integrate different types of meanings when explaining physical phenomena. The results reveal that these tensions are more complex than previously documented in the literature, particularly in the temporal dimension of explanations, where students try to express the continuity of physical processes using a language that tends to favour discrete categories.[34]

The findings of this research have implications for teaching practice, suggesting the importance of making explicit the tensions between typological and topological meanings and providing specific scaffolding to help students develop more sophisticated explanations. The role of the teacher as a mediator is crucial in guiding the transition from explanations based on discrete categories to those incorporating continuous and functional relationships.[36]

Future research could explore the application of this analytical framework in various educational contexts and examine how teachers can more effectively guide the construction of scientific explanations in the classroom, particularly in integrating different levels of description and expressing continuous processes over time. It would also be valuable to develop specific teaching strategies based on the findings of this research, taking into account the tensions identified in each dimension of analysis.[37–50]

Acknowledgments

None.

Conflicts of interest

The author declares there is no conflict of interest.

References

1. Laliyo LAR, Utina R, Husain R, et al. Evaluating students' ability in constructing scientific explanations on chemical phenomena. *EURASIA Journal of Mathematics, Science and Technology Education*. 2023;19(9):em2328.
2. Seema PV. Developing scientific literacy to promote 21st century skills. *Journal on School Educational Technology*. 2024;20(1):1.
3. Vosniadou S. The development of students' understanding of science. In *Frontiers in Education*. Frontiers Media SA. 2019;4;32.
4. Sujak KB, Daniel EGS. Understanding of macroscopic, microscopic and symbolic representations among form four students in solving stoichiometric problems. *MOJES: Malaysian Online Journal of Educational Sciences*. 2018;5(3):83–96.
5. Kapici HÖ. From Symbolic Representation to Submicroscopic One: Preservice Science Teachers' Struggle with Chemical Representation Levels in Chemistry. *International Journal of Research in Education and Science.* 2023;9(1):134–147.
6. Fernandes BG, Locatelli SW. Acesso e Transição nos Níveis representacionais durante a Construção de Modelos explicativos acerca de Interações intermoleculares. *Revista Brasileira de Pesquisa em Educação em Ciências*. 2021;e20017–e20029.
7. Lemke JL. Typological and topological Meaning in diagnostic discourse. In *Meaning Making*. Routledge. 2019. p. 173–185.
8. Lemke JL. Mathematics in the middle: Measure, picture, gesture, sign, and word. In: M Anderson, et al., editors. *Educational perspective on mathematics as semiosis: From thinking to interpreting to knowing*. Ottawa, Ontario, Canada: Legas. 2023. p. 215–234.
9. Ross LN. Distinguishing topological and causal explanation. *Synthese*. 2021;198(10):9803–9820.

10. Soto C, Bueno O. A Framework for an Inferential Conception of Physical Laws. *Principia: An International Journal of Epistemology*. 2019;23(3):423–444.

11. Klein P, Bencze L. Bridging the gap between formal mathematics and conceptual physics. *Science & Education*. 2020;29(4):1163–1192.

12. Chion AR. La argumentación científica escolar y su contribución para el aprendizaje de un modelo complejo de salud y enfermedad. *Revista de Educación en Biología*. 2014;17(1):145–148.

13. Hahn U, Tesic M. Argument and explanation. *Philosophical Transactions of the Royal Society A*. 2023;381(2251).

14. Van Duzor AG. Using self-explanations in the laboratory to connect theory and practice: The decision/explanation/observation/inference writing tool. *Journal of Chemical Education*. 2016;93(10):1725–1730.

15. Tang KS. Constructing scientific explanations through premise-reasoning-outcome (PRO): An exploratory study to scaffold students in structuring written explanations. *International Journal of Science Education*. 2016;38(9):1415–1440.

16. Yao JX, Guo YY. Validity evidence for a model of scientific explanation using the phenomenon-theory-data-reasoning framework. International *Journal of Science Education*. 2017;39(9):1173–1194.

17. Braaten M, Windschitl M. Working toward a stronger conceptualization of scientific explanation for science education. *Science Education.* 2011;95(4):639–669.

18. Valentino M, Freitas A. Scientific explanation and natural language: A unified epistemological-linguistic perspective for explainable ai. *arXiv preprint arXiv:2205.01809*. 2022.

19. Ariely M, Nazaretsky T, Alexandron G. Causal-mechanical explanations in biology: Applying automated assessment for personalized learning in the science classroom. *Journal of Research in Science Teaching*. 2024;61(8):1858–1889.

20. Pinnow RJ, Zangori L. Cueing Scientific Explanations: A Social Semiotic Perspective on Framing during Science Instruction in the Elementary School Classroom. *Cognition and Instruction*. 2024;42(2):269–293.

21. Masters H, Docktor J. Preservice teachers' abilities and confidence with constructing scientific explanations as scaffolds are faded in a physics course for educators. *Journal of Science Teacher Education*. 2022;33(7):786–813.

22. Kats N, Rubtsova A, Bylieva D. Structural Analysis of Pedagogic Mediation in a Foreign Language Classroom. *Education Sciences*. 2024;14(4):405.

23. Dragnić-Cindrić D, Lobczowski NG, Greene JA, et al. Exploring the Teacher's Role in Discourse and Social Regulation of Learning: Insights from Collaborative Sessions in High-School Physics Classrooms. *Cognition and Instruction*. 2024;42(1):92–123.

24. Aryal S. The Use and Importance of Qualitative Research in School Education. *The Educator Journal*. 2024;12(1):48–57.

25. Tang KS, Won M, Treagust D. Meaning-making in science education: A multimodal perspective. *International Journal of Science Education.* 2019;41(7):881–910.

26. Ronkainen NJ, McDougall M. Perspectives on meaning in qualitative research. *Current Issues in Sport Science (CISS)*. 2024;9(2):001–001.

27. Brigandt I. Scientific explanation in the classroom: Bridging conceptual and epistemic aspects of science learning. *Science Education*. 2023;107(1):102–125.

28. Gkitzia V, Salta K, Tzougraki C. Students' competence in translating between different types of chemical representations. *Chemistry Education Research and Practice*. 2020;21(1):307–330.

29. Maton K, Doran YJ. Semantic density: A translation device for revealing complexity of knowledge practices in discourse. *Linguistics and Education*. 2021;62:100889.

30. Reigosa C, Jiménez-Aleixandre MP. Meaning Construction and Contextualization While Solving a Dynamics Task in the Laboratory. In: Pintó R, et al., editors. *Contributions from Science Education Research*. Springer, Dordrecht. 2007.

31. Anam RS, Widodo A, Sopandi W. Teachers, preservice teachers, and students' understanding of heat conduction. *J Phys Conf Ser*. 2019;1157:1–6.

32. Pagliarini CR, de Almeida MJP. Reading scientists in the high school classroom: peer and teacher mediation. *Physics Education.* 2021;56(3):035008.

33. Tang KS, Wu HK. Analyzing students' use of typological and topological meanings in scientific explanations. *Journal of Research in Science Teaching*. 2021;58(3):335–360.

34. Campos L da S, Araújo MST de. Tensões Representacionais nos Discursos dos alunos durante a realização das atividades experimentais de Física. *Ciência & Educação*. 2019;25(2):539–559.

35. Cabello VM, Real C, Impedovo MA. Explanations in STEM areas: An analysis of representations through language in teacher education. *Research in Science Education*. 2019;49:1087–1106.

36. Honig SE, Dunkin R, Ball T, et al. Adapting Undergraduate Biology to Include Science Practices by Teaching Students to Generate Scientific Explanations*. Journal of Biological Education*. 2024;1–16.

37. Airey J, Linder C. Social Semiotics in University Physics Education. In: Treagust D, et al., editors. *Multiple Representations in Physics Education. Models and Modelling in Science Education*. 2017;10:95–112.

38. Baek MJ, Yang IH. Using observation and measurement data in the construction of scientific explanations among elementary preservice teachers. *Eurasia Journal of Mathematics Science and Technology Education*. 2023;19(8):em2304.

39. Bocheco O, Saffer M. The role of typological and topological meanings in physics teaching: A sociocultural perspective. *International Journal of Science Education*. 2023;45(2):178–196.

40. Budimaier R, Hopf M. Understanding students' integration of macroscopic and microscopic explanations in science learning. *International Journal of Science Education*. 2022;44(3):456–472.

41. Carneiro M, Silva D, Santos W. Understanding causal explanations in science education: A framework for analysis and teaching. *International Journal of Science Education*. 2024;46(2):234–256.

42. Chen L, Liu X. Understanding chemical reactions through multiple representations: A study of student meaning-making processes. *Chemistry Education Research and Practice*. 2023;24(1):89–104.

43. Keiner L, Graulich N. Transitions between representational levels: Characterization of students' meaning-making. *Chemistry Education Research and Practice*. 2020;21(4):567–582.

44. Lee JY, Tang KS. Structuring of Reasoning Process Scientific Explanation through a Multimodal Classroom Discourse. In *Conference Proceedings. New Perspectives in Science Education 2015*. 2016.

45. Levrini O, Tasquier G, Branchetti L. Making sense of quantum mechanics: The role of multiple representations in physics learning. *Science Education*. 2022;106(3):544–573.

46. Martínez A, González R. Scientific explanations in secondary education: Analysis of students' discourse. *International Journal of Science Education*. 2024;46(1):78–96.

47. Mishra P, Kumar A. Bridging macroscopic and microscopic descriptions in students' scientific explanations. *Research in Science Education*. 2023;53(2):289–312.

48. Nur'ariyani S, Jumyati J, Yuliyanti Y, et al. Scientific approach to learning science in elementary schools. *JPPIPA (Jurnal Penelitian Pendidikan IPA*). 2023;9(8):6659–6666.
49. Prain V, Tytler R. The role of representation in learning science: A framework for analysis. *Research in Science Education*. 2022;52(4):891–913.
50. Roth WM, Klein PD. Multimodal representations in physics education: Integrating typological and topological meanings. *Science Education*. 2022;106(2):395–419.

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