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Research Article

Exploring semantic gravity in physical chemistry teaching: a case study in secondary education

Summary

This study investigates how a Chemistry Teacher Training College resident teacher uses his discourse to define key concepts such as "substance" and "solution" in a second-year Physical Chemistry course in Secondary Education in the Province of Buenos Aires. Framed in Karl Maton's Legitimacy Code Theory (LCT), the study focuses on the semantic dimension, examining how variations in semantic gravity (SG) affect the teaching and learning of scientific concepts in science classrooms. The methodology is qualitative, based on an instrumental case study that analyzes discursive exchanges between teachers and students. Classes were recorded and transcribed for detailed analysis using a specific translation device to map oscillations between strong and weak SG. The results indicate that variations in GS, in the context of discursive interactions, allow educators to begin with concrete, observable examples to establish a solid foundation of empirical understanding before moving toward abstract definitions that foster more critical and generalized thinking. This study contributes to advancing theoretical knowledge about LCT and GS and offers practical implications for improving pedagogical strategies in science teaching. By providing a replicable model, this work can be adapted by other educators and researchers interested in optimizing conceptual learning in science.

Keywords: semantic gravity, chemistry teaching, legitimation code theory, definition in physical chemistry

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Abbreviations: LCT, legitimacy code theory; SG, semantic gravity

Introduction

Teaching scientific concepts in secondary education is fundamental to developing students' deep and meaningful understanding of the natural world. In particular, teaching notions such as "substance" and "solution" in the field of Physical Chemistry represents a challenge due to their abstract nature and the need to connect these concepts with concrete experiences.[1] The Legitimation Code Theory (LCT), proposed by Karl Maton, offers a robust theoretical framework to analyze how knowledge is constructed and communicated in educational contexts.[2] Within LCT, the semantic dimension is crucial to understanding how variations in semantic gravity (SG) influence the teaching and learning of scientific concepts.[3]

Despite advances in educational research, significant gaps remain in understanding how teachers can effectively manage transitions between different levels of GS to facilitate conceptual learning.[4] By addressing these gaps, this study contributes to advancing theoretical knowledge about LCT and GS and offers practical implications for improving pedagogical strategies in the classroom.

The importance of this research lies in its potential to transform educational practices through the conscious application of semantic profiles that oscillate between strong and weak GS. This approach allows educators to begin with concrete, observable examples to establish a solid foundation of empirical understanding before transitioning to abstract definitions that foster more critical and generalized thinking.[5] By providing a detailed analysis of how these discursive transitions are managed, this study offers a replicable model that can be adapted by other educators and researchers interested in optimizing conceptual learning in science.

This research aims to analyze how a Chemistry teacher, through his verbal discourse, conveys, in terms of variations in semantic gravity (SG), the construction of the definitions of "substance" and "solution" during discursive interactions in a second-year Physical Chemistry course (with students aged between 13 and 14 years) of Secondary Education in the Province of Buenos Aires. By addressing this issue, we aim to advance theoretical knowledge on the Legitimacy Code Theory (LCT) and offer practical implications to improve pedagogical strategies in science teaching.[4]

The methodology used in this study is qualitative and based on an instrumental case study. It focuses on the discursive exchanges between a teacher and his students during a Physical Chemistry class. A specific translation device was used to map the oscillations between different intensities associated with GS.[6] This approach allows a clear visual representation of how scientific knowledge is constructed and communicated, providing a structured framework for analyzing teaching practices.

LCT in educational research

Legitimation Code Theory (LCT), developed by Karl Maton, offers a robust theoretical framework for analyzing how knowledge is constructed and legitimized in diverse educational contexts. This theory addresses the organizational principles underlying knowledge practices, exploring how they are structured and assessed across different disciplines.[2] Within LCT, the semantic dimension is particularly relevant because it examines how knowledge varies regarding semantic gravity (SG) and semantic density (SD). SG measures the degree to which meaning is linked to a specific context: a strong SG (SG+) indicates highly contextualized knowledge. At the same time, a weak SG (SG-) represents more abstract and generalizable knowledge.

Numerous studies have applied the semantic dimension of LCT to analyze educational practices. Maton and Doran[3] introduced semantic waves to map oscillations between GS+ and GS- in educational discourse. These oscillations connect concrete experiences with theoretical abstractions, facilitating cumulative learning. This approach has proven effective in various disciplines, including natural sciences, history, and mathematics.

In physics education, Georgiou et al.[2] explored how variations in GS affect the understanding of complex concepts such as thermodynamics. Their study highlighted the "Icarus effect," where students reach inappropriate levels of abstraction for specific questions. This underscores the importance of strategically adjusting GS to facilitate meaningful connections between theory and practice. Similarly, Conana et al.[7] analyzed pedagogical practices in university physics courses, highlighting how transitions between abstract and concrete representations enhance student understanding.

In chemistry, dos Santos and Mortimer[8] demonstrated that semantic waves can facilitate understanding fundamental concepts by integrating macroscopic and submicroscopic levels. This approach helps students connect direct observations with theoretical explanations, promoting deeper learning. Vargas and Ortega[9] also analyzed how semantic profiles ranging from GS+ to GS- can improve student performance in science. They found that dynamic teacher discourse significantly facilitates conceptual learning by allowing students to apply scientific principles in diverse contexts.

In addition, recent research has explored specific applications of LCT in other disciplines. Waite et al.[4] investigated how semantic waves can be applied in computer science education to improve understanding of abstract concepts through hands-on activities. Tang and Rappa[5] reviewed the role of language in the science classroom, highlighting how variations in GS influence the effectiveness of scientific communication.

Moraga-Toledo and Espinet-Blanch[10] underline the importance of semantic waves in promoting deep understanding by integrating abstract concepts with practical experiences. Their study highlights how transitions between different levels of GS can facilitate or hinder conceptual understanding, allowing students to develop a more flexible understanding of scientific knowledge.

Brooke et al.[11] demonstrated that combining scientific and everyday discourses improves student understanding by contextualizing complex concepts. Langsford and Rusznyak[12] on the other hand, explored how integrating SG into teacher education programs can improve pedagogical practices by preparing future educators to manage discursive transitions effectively.

Although these studies have significantly advanced our understanding of LCT and GS, important gaps remain. For example, more research is still required on how these practices can be adapted to different educational levels or cultural contexts. Furthermore, it is necessary to explore how cultural and institutional variations affect the practical implementation of the theoretical framework. In this context, the present study seeks to advance theoretical knowledge of LCT by analyzing how a teacher conveys scientific concepts during discursive interactions in the classroom. By mapping the oscillations between GS+ and GS-, this work provides a replicable model that can be adapted by other educators and researchers interested in optimizing conceptual learning in science.

Theory of the code of legitimacy

Legitimation Code Theory (LCT), proposed by Karl Maton, is a theoretical approach that seeks to understand how knowledge is constructed and legitimized in diverse educational contexts. LCT focuses on knowledge practices and how these are structured and evaluated within specific fields. LCT offers a robust framework for analyzing knowledge practices in educational settings.[2]

LCT is organized into several dimensions that explore different organizing principles underlying practices, dispositions, and contexts. So far, the three most elaborated dimensions are Specialization, Semantics, and Autonomy.[2,3] This paper will focus on the semantic dimension, which is fundamental to understanding how knowledge is constructed and communicated in educational contexts.

In the context of LCT, the Semantics dimension explores how knowledge is constructed and understood through the interaction of two key concepts: semantic gravity and semantic density. Semantic gravity (SG) refers to the degree to which meaning is context-dependent. Strong semantic gravity (SG+) indicates that knowledge is closely tied to specific contexts, making it more concrete and practical. In contrast, weak semantic gravity (SG-) suggests that knowledge is abstract and generalizable, allowing it to transcend particular contexts.[2,3]

On the other hand, semantic density (SD) refers to the complexity and condensation of meaning within a concept. High semantic density implies that a concept encapsulates multiple layers of meaning, often requiring sophisticated understanding and interpretation. Low semantic density indicates more straightforward meanings with less complexity.[2] Together, these dimensions form the basis for understanding how knowledge is constructed and communicated in educational contexts. In this paper, we analyze teacher-led discursive interactions in a physical chemistry classroom, focusing on GS and the temporal variations of this concept in the semantic profile.

The notion of a semantic profile is also integral to this analysis. A semantic profile maps semantic gravity and density variations across a lesson or series of lessons. It visually represents how knowledge is structured over time, highlighting moments where teaching practices reinforce or challenge student understanding.[3] By examining these profiles, educators can identify opportunities to enhance the cumulative construction of knowledge, where new knowledge is integrated with existing understanding to form a coherent whole.[4] Semantic profiles allow different movements of GS to be visualized. The most characteristic ones are written down and exemplified below.

An oscillating movement between stronger and weaker levels of semantic gravity characterizes the Semantic Waves profile. In a solution lesson, a teacher might begin with a practical demonstration using water and oil to illustrate homogeneous and heterogeneous mixtures representing a strong GS (GS+). Then, the teacher might move into a theoretical discussion on the molecular nature of solutions, introducing abstract concepts such as the interaction between solute and solvent, reflecting a weak GS (GS-). Finally, the teacher might return to concrete examples by asking students to perform experiments in the laboratory to directly observe these phenomen.[3] In GS terms, semantic waves describe the movement between stronger and weaker semantic gravity within educational discourse. This oscillation is crucial for effective teaching and learning, as it allows students to connect concrete experiences with abstract concepts, thus facilitating

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deeper understanding.[3] By engaging with specific details and broader abstractions, students can develop a more complete understanding of the topic.[13] These moves are represented in Figure 1.

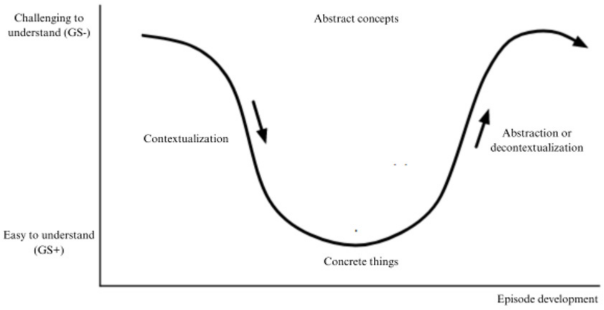

Figure 1 Semantic wave for GS. Source: adapted from Waite et al.[4]

With its high flatlining profile, the GS remains at a vigorous intensity. A practical example would be a lesson focused exclusively on laboratory activities, where students observe and describe chemical reactions without introducing too much abstract theory. This approach helps establish a solid foundation of empirical observations before introducing more abstract concepts. For example, students could measure the pH of different solutions using visual indicators and discuss their observations without delving into theoretical explanations of pH.[9]

In a profile of low flatlining, GS remains consistently weak. In an advanced theoretical chemistry course, a teacher might devote an entire class to discussing mathematical models describing molecular interactions in solutions without referencing concrete examples. This approach is suitable for students who already have a solid understanding of the basic concepts and are prepared to explore complex theories without needing immediate contextual anchors.[10]

Taber's[14] proposal on the distinction between the macroscopic and submicroscopic levels in chemistry teaching is recovered for the present work. The macroscopic level refers to the phenomena of the external world that we can directly perceive, such as substances, movements, attractions and chemical reactions. This level is fundamental for the initial teaching of scientific concepts, providing a tangible base for students to build their understanding. On the other hand, the submicroscopic level encompasses entities such as molecules, ions and electrical interactions, which are not directly observable but are essential to explain macroscopic phenomena.

Integrating these levels in science teaching allows students to develop a more complete and deeper understanding of chemical concepts. Inscribing the tangible in the perceived phenomena of the external world facilitates the bridge to understanding the underlying structures that explain these phenomena. This duality fosters meaningful learning, allowing students to connect their everyday observations with more abstract scientific theories.

Defining in the science classroom

Concept definition is a central cognitive procedure in science teaching. In science classrooms, teachers frequently define concepts in different teaching contexts, whether during an explanation, an example, an experimental activity, or in response to students' questions; the definition constitutes a didactically naturalized instance.

According to Teig (2021), defining is expressing the necessary and sufficient characteristics so that the concept cannot be confused with another, with the help of other terms that are assumed to be known. For Liu & Kinyota (2021), the definition is a descriptive and affirmative text with no doubts or uncertainties. Defining means establishing similarities and differences, grouping them by categories and subcategories, recognizing essential properties, and producing a text with adequate terminology.

We also define a concept in different ways. We propose diverse approaches to students and different approximations, even during the same discursive intervention. From these interventions, we propose diverse conceptual constructions under the same terms. The definition can be defined by operationalization, based on a mathematical model, and from the conceptual relationships between terms specific to a school scientific model. Different degrees of conceptual approximation can be offered from each of these alternatives. These different approaches are essential in science classrooms, as they delimit scopes that could facilitate/hinder access to learning. In the context of the different instances of content concretion, during the recontextualization process (Krause et al., 2021), it would not only be a matter of planning what concept to teach; it would also matter, especially how it is taught.

School science teaching should promote learning of school scientific models with a progressive level of complexity, allowing students to access successive conceptual constructions of increasing complexity.[5] In this process of successive constructions, these models offer students reference frameworks for observing and interpreting phenomena. An event can be interpreted from different approaches and re-signified at different times in this process, in instances of increasing depth that allow phenomena to be approached from different thematic patterns.[15] Each of these constructions is instituted, at different times during schooling, as a privileged way of speaking, reading and writing in the science classroom. The teacher then appears as a guide to mental worlds that are new to students (Sutton, 2000).

Words such as "solutions", "substance", and "chemical change", Brooke et al.[11] argue, are not understood just by reading their definition or a brief description included in a textbook. They acquire meaning when they have been discussed, read, experienced, and discussed. With this last consideration from teaching practices, the teacher's discursive interventions would be presented as a privileged vehicle to enable instances of understanding concepts by offering different contexts from which to approach students to construct the concept. Following Lemke[15] through different modalities of discursive interventions, the teacher can present the same set of concepts structured in different thematic patterns according to the demands of the educational contexts. However, since the thematic pattern is constructed through language, the students' appropriation requires verbalizing it. The discursive interventions of the teacher, through his presentations, answers, and explanations, are not established as a necessary and sufficient condition for learning. Listening is not a sufficient process, although learning science in the classroom is necessary. However, many teachers must spend more time teaching semantic relationships between concepts.[15] In addition, students have difficulty grasping semantic relationships because, on many occasions, teachers do not stop to make them explicit; we take for granted known issues that are not clear in students' minds. Moreover, during teaching practices, the definition is often presented as a text in which the implicit dominates the scene. Just as the description implies specifying the "way of looking at" the phenomenon under study, the aspects to focus the observation,[5] the definition previously places the concept in the context of a thematic pattern that will guide the observation.

In this work, we analyze how a resident teacher of the Chemistry Teaching College conveys, through his verbal discourse, the definition of “substance” in a Physical Chemistry course corresponding to the second year of Secondary Education in the Province of Buenos Aires.

Methodology

The work is based on a qualitative methodology and an instrumental case study (Stake, 2007) where the case corresponds to the discursive exchanges developed between a Chemistry teacher and students (13-14 years old) during a Physical Chemistry class belonging to the second year of Secondary Education, Province of Buenos Aires, in which the treatment of the notion of “substance” and “solution” is addressed. The class is part of a didactic unit called “solutions” and is the first of six. The classes were recorded in audio and video and transcribed in their entirety. Each class was divided into episodes based on the topic changes and the activity’s structure. The class analyzed in this work was divided into six episodes. In this work, we consider the first of them, during which the intern introduces the concepts of “substance” and “solution”.

In the field of LCT, a “ translation device “ acts as a bridge between theoretical knowledge and its practical application, enabling researchers and educators to translate complex concepts into effective pedagogical strategies (Singh, 2015). By providing a structured framework for this integration, the translation device helps ensure that theoretical principles are applied coherently and effectively in the classroom.[2,3] This is especially relevant in contexts where educational theories may seem distant or abstract to educational practitioners.

In the context of the present research, which focused on the notion of semantic gravity (SG) within the framework of Legitimacy Code Theory (LCT), a specific translation device was developed to analyze how teachers manage variations in SG during discursive interactions in the classroom (Table 1). This device allowed mapping the oscillations between strong (SG+) and weak (SG-) semantic gravity throughout the episode, providing a clear visual representation of how scientific knowledge is constructed and communicated.[6]

Table 1 Translation device for GS. Source: Own elaboration

	Mode	Definition	Examples
Increase in GS intensity ↑	GS+	Interactions are highly contextualized, with a focus on concrete, observable examples.	- Direct empirical examples, such as water and oil, illustrate homogeneous and heterogeneous mixtures. - Questions and answers that depend on the immediate context, facilitating initial understanding through direct observation.
	GS0	Interactions maintain a balance between the concrete and the abstract, neither strongly linked nor utterly detached from the context.	- Use visual schemes or metaphors that connect the observable with the abstract, such as using a magnifying glass to view microscopic particles. - Transitions between concrete examples and conceptual generalizations, allowing students to integrate empirical experiences with broader understandings.
	GS-	Interactions are highly abstract, detached from specific contexts and generalizable to multiple situations.	- Discussions focused on theoretical principles or conceptual models without directly referencing concrete examples.

In order to ensure the transferability of the results, a detailed description of the educational context in which the study is conducted has been provided. During the research, the teacher was observed to use a series of carefully planned pedagogical strategies to introduce the concepts of “substance” and “solution”. These strategies were documented through audiovisual recordings and detailed transcripts of classroom interactions. The teacher used various teaching resources such as a practical demonstration (for example, using water and oil to illustrate homogeneous and heterogeneous mixtures), examples of concrete liquids, and visual diagrams. The intention of providing a detailed record of the activities and resources is understood as a valuable resource for other educators and researchers who wish to replicate or adapt these practices in their classrooms. This approach allows the results to be applicable beyond the immediate context of the study, contributing to the broader field of science education by offering a replicable model for teaching complex concepts through the conscious use of semantic gravity as a teaching category to analyze teaching practices. They allow other educators to assess whether the findings are relevant to their contexts.[16]

Credibility was sought to be strengthened through triangulation by combining direct classroom observations with audiovisual recordings and combining these recordings with full class transcripts. This allowed results to be corroborated across different data sources, ensuring that interpretations are consistent and accurate.[17]

Results

In the analysis of the class episode on the notion of “substance”, it was observed how the teacher used different GS modalities throughout the discursive interactions, reflecting variations in the level of abstraction and contextualization of the content. The class began by focusing on concrete examples, from which the teacher introduced the topic of “solutions” by reviewing previous concepts on homogeneous and heterogeneous mixtures. This beginning was characterized by a strong semantic gravity (GS+), as he used empirical examples such as water and oil to explain these mixtures, allowing students to anchor their understanding of indirect observations. A clear example of this modality is found in the following fragment:

> **4.** D: The first thing we will see is the concept of substance [writing on the blackboard].
>
> We saw in the review guides that we could differentiate two types of mixtures:
>
> Homogeneous mixtures and heterogeneous mixtures, do you remember anything about that? That the
>
> We could differentiate according to the number of phases in each one, for example
>
> For example, in a homogeneous system, how many phases were there?
>
> **5.** Class: One
>
> **6.** D: Only one. Is the case of water a homogeneous system? Or heterogeneous?
>
> **7.** Class: Homogeneous
>
> **8.** D: Homogeneous, perfect, good. Why? Because it has only one phase. In the case of heterogeneous systems…?

9. Class: two or more…

10. D: Two or more phases, is that OK? For example, if I mix water and oil?

11. A2: There are 2 phases

12. D: There are two phases; the oil will be above the vessel. In this fragment, the interaction focuses on direct and tangible observation, facilitating initial access to the concept through concrete examples.

The analysis of the following sequence of exchanges between the teacher and the group of students (lines 13 to 27) allowed us to see how the teacher used various discursive strategies to facilitate the understanding of the concept. This sequence was characterized by a transition from a strong semantic gravity (GS+) to a more neutral one (GS0) and finally to a weak semantic gravity (GS-), reflecting a change in the level of abstraction and contextualization of the content. This sequence began with the teacher introducing the concept of "substance" through the example of water, a homogeneous system with a single phase. The teacher poses a hypothetical situation to help students visualize the particles that makeup water, using a visual scheme that simulates a magnifying glass to observe the particles in the liquid. This scheme allowed the observable to be connected to the abstract and expresses a semantic gravity (GS0), which transits between the concrete and the abstract by using an imaginary magnifying glass to help students visualize the microscopic particles of water:

" Now *let us delve into the concept of substance, analyzing water, for example. As you said, water is a homogeneous system with only one phase. What happens if I make myself very small and start to see the particles… that make up water? I brought you a diagram so you do not have doubts about the case of water [shows a diagram representing a container containing water and, simulating through a magnifying glass, the particles in the liquid]. Look, here I have a glass. Let us suppose I am tiny and can see the particles that make up water* (line 13).

In this last intervention, the teacher facilitated a transition (from a GS+) to a more abstract level (GS0), allowing students to integrate empirical experiences with broader understandings. Using the visual scheme as a bridge between the macroscopic and microscopic levels helps students conceptualize at the latter level, and visualization is used to connect the observable with the abstract. The teacher continued to reinforce the idea that all particles in water are the same, thus establishing the definition of "substance" as a homogeneous system made up of identical particles:

"They are the same, OK? Any doubts about this? If I make myself very small, each water particle will equal the other. Yes? Good. In that case, we are talking about water being a substance... Why? Because it is a homogeneous system, it has only one phase, but also, it is composed of particles that are equal to each other. OK? That is to say, what properties does the substance have? All the particles composing it are equal" (line 15).

This last intervention illustrates how the teacher used questions to consolidate students' understanding of the concept. The interaction culminates with a formal definition of the concept of "substance" written on the board (" *So, let us define substance as, [writing on the board] 'a homogeneous system... made up of identical particles* '", line 18), which represents a move toward weak semantic gravity (WSG) by generalizing the definition beyond specific examples.

Finally, the teacher exemplified the notion of "substance" using another liquid, alcohol, by showing how the particles of alcohol are different from those of water but equal to each other within the same substance ("[…] *Alcohol* [showing the group a glass containing alcohol] *is another example of a substance. What are the particles that makeup alcohol going to be like, then?... They will not be the same as those of water* "; line 19). In this last fragment, the differentiated understanding between substances is reinforced based on their microscopic characteristics, using an empirical referent that allows students to conceptualize differences between substances through visualization and direct comparison (GS+). In this instance, the teacher uses a concrete referent by physically showing the alcohol and asking about its characteristics, which reflects a strong semantic gravity (GS+). The interaction focuses on observable and tangible examples, facilitating initial understanding through direct observation.

However, when the teacher uses a new visual scheme to illustrate how the alcohol particles are different from those of water but equal to each other, a transition to a new modality of semantic gravity (GS0) is observed:

" *I brought you another diagram here [shows a diagram in which a container containing alcohol is drawn and simulating the particles in the liquid through a magnifying glass], where you can see, for example, a bottle of alcohol and inside, if we made ourselves very small we could see these particles that are identical to each other*." (line 23).

The teacher interrupts this level of contextualization (GS0) by weakening the intensity of the GS by abstracting the content of his speech ("*Each substance has different particles concerning other substances. That is why they are different substances. If they had identical particles, they would be the same substance, right? The important thing is that each substance, in the same substance, the identical particles are found, among themselves* ", line 28), moving away from empirical referents. However, he then recalls the visual scheme to explain that the particles of water and alcohol are different because they are different substances. On this occasion, the teacher reinforces this differentiated understanding based on microscopic characteristics and sustains the discursive exchange in a GS0:

" *Here, all the particles that make up the water are going to be equal to each other, and all the particles that make up the alcohol are going to be equal to each other, but between the alcohol and the water, the particles are different because they are different substances, right?"* (line 29).

After having previously defined the concept of "substance" and having given examples with water and alcohol, the teacher presented the group of students with a demonstration that consisted of mixing these two substances in a container. At this point in the episode, the discursive exchange with the group increased the intensity of the GS (GS+) when the teacher asked the students to observe what happens when water and alcohol are mixed:

"So we have already given two examples, water and alcohol. Let us see what happens if I mix water with alcohol. Let us put a certain amount of water in the glass... OK? Moreover, let us put a little less alcohol and see what happens [mixes both liquids in a glass showing it to the group] Good. Look, now, it is a mixture of two solutions that we have already seen: water and alcohol. Is a homogeneous system formed or a heterogeneous system? " (line 30).

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In the last sequence of the episode (lines 30 to 50), the teacher moved between different GS modalities to facilitate conceptual understanding. This sequence began with the teacher proposing a practical activity that involves mixing water and alcohol, two substances previously discussed, focusing attention on concrete empirical referents and allowing students to directly observe the result of the mixture (GS+) ("*OK. Now, look, it is a mixture between two solutions that we already saw, water and alcohol. Is a homogeneous system formed or a heterogeneous system*", line 30). He used this mixture as a referent of a homogeneous system to introduce the notion of "solution" ("*So, when we mix two substances, and we get a homogeneous mixture, we are talking about a solution. We arrive at the concept we will work on in these classes. That is, is the solution a homogeneous mixture, OK?*", line 34). Once the concept of "solution" was introduced, in a new discursive exchange, the teacher increased the intensity of the GS (GS0) by bringing the group of students' attention back to the mixture of water and alcohol. However, this time, I represented it in a diagram on the blackboard (" *Look, I had drawn the alcohol with black particles and the water with greyer particles. Exactly, they mix and form a homogeneous system, which will look something like this, look... [shows a diagram showing a container containing both liquids and, using a magnifying glass to simulate water and alcohol particles represented in different colours]",* line 38). Finally, in this part of the episode, he abstracts the content of his speech by proposing a new instance for conceptualizing the notion of "solution":

39. D: [...] Well, then, what did I do here…? I mixed water and alcohol, and what did I get? A system,

a homogeneous mixture or a heterogeneous mixture?

40. Class: A homogeneous mixture

41. D: A homogeneous mixture, very good. [on the board, completing the diagram,

represent a "+" between the words "alcohol" and "water"; then include them in a

key under which write "homogeneous mixture"]. As we said, this was called

a homogeneous mixture.

42. Class: Solution

43. D: Perfect, this homogeneous mixture is equal to the concept of "solution" [writing the word "solution" on the board].

Ending the episode, the teacher introduced the concepts of "solvent" and "solute" in a solution, directly linking them to the relative amount of each component in the mixture ("The *last thing we are going to see now [...] is that all solutions are composed of at least two components, as we just saw. In the case of this solution [showing the glass containing the mixture of water and alcohol], what are the components?* ", line 44). In this intervention, the teacher moved towards a strong semantic gravity (GS+) by explaining these terms and their differences through specific examples, such as the quantity of water and alcohol in the mixture, to then weaken the GS by abstracting from the concrete referents (GS-) (" *The components of a solution are called: solvent and solute [writing both words on the board] What is the difference between one and the other? The solvent is the one found in greater quantity",* line 46). Once again, he recovered the example of the water-alcohol mixture (" *And the solute is the one found in lesser quantity. In that case, what was it?* ", line 46) to finally place the exchange at a level of conceptualization defined by a weak GS (GS-) (" *That is to say that solutions always go... what you are going to work on is that they are composed of two types of components, the solvent in greater quantity, solute in lesser quantity* ", line 50).

Figure 2 presents the semantic profile corresponding to the GS variations identified during the discursive exchanges between the teacher and the students in the episode considered.

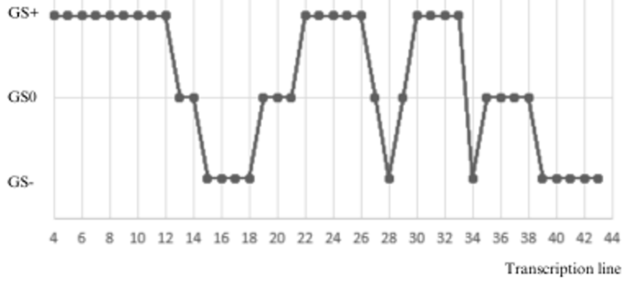

Figure 2 Semantic profile for GS. Source: own elaboration.

Discussion of results

In this section, the theoretical contributions of the study are analyzed, highlighting how oscillations between strong (GS+) and weak (GS-) semantic gravity facilitate conceptual learning. Likewise, practical applications derived from the results are presented, offering concrete pedagogical strategies to optimize the teaching of abstract concepts. Finally, the limitations of the theoretical and methodological framework are reflected upon, paving the way for future research. This structure seeks to provide a comprehensive view of the study's contributions to the educational field and its relevance in scientific contexts.

Theoretical implications

This research provides new perspectives on the theoretical framework of the Legitimation Code Theory (LCT), particularly in its semantic dimension. This study confirms that oscillations between strong (GS+) and weak (GS) semantic gravity are crucial in constructing scientific knowledge in the classroom. The findings reinforce Maton and Doran's[3] proposals on semantic waves as fundamental tools to connect concrete experiences with theoretical abstractions. In this context, it was observed how the teacher used empirical examples, such as homogeneous and heterogeneous mixtures, to anchor initial learning in observable contexts before moving towards abstract definitions that foster a more generalizable understanding.

Furthermore, this work extends the theoretical scope by highlighting how semantic profiles can map variations in GS during discursive interactions. This provides a robust analytical tool to assess how knowledge is constructed in real-time, offering a clear visual representation of semantic dynamics in the classroom. Previous studies, such as those by Georgiou et al.[2] and Conana et al.,[7] have explored similar applications in scientific disciplines. However, this study contributes to the field by focusing its analysis on the teaching of fundamental chemical concepts such as "substance" and "solution". Thus, the usefulness of the LCT theoretical framework for analyzing specific educational practices is validated. New avenues are opened for investigating how these dynamics can be replicated or adapted in other educational contexts.

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Practical applications

From a practical perspective, the findings of this study offer concrete teaching strategies to improve the teaching of abstract concepts in science. One key strategy identified is to start with observable empirical examples (GS+), such as mixing water and oil, to establish a solid foundation of initial understanding. As students become familiar with these basic concepts, it is recommended that they gradually move towards abstract definitions using visual tools and metaphors that connect the observable with the theoretical.[3] This approach facilitates conceptual learning and promotes a more flexible understanding that allows students to apply scientific principles in diverse contexts.

For example, during this study's analysis of teacher discourse, it was observed how the strategic use of guided questions helped students conceptualize abstract notions beyond specific examples. This finding is consistent with previous research highlighting the importance of semantic waves in integrating abstract concepts with practical experiences.[8,9] Educators can design activities that oscillate between GS+ and GS by implementing these pedagogical strategies based on semantic profiles, thus optimizing conceptual learning.

Limitations of the semantic gravity framework

Despite its significant contributions, this study presents important limitations that must be considered. First, it is based on a single case study focusing on a teacher and a specific group of students in the Province of Buenos Aires. This limits the generalizability of the findings to other educational contexts or scientific disciplines. Furthermore, although semantic waves offer a helpful framework for analyzing teaching practices, their implementation can be challenging due to individual differences in pedagogical skills and institutional conditions.

Another area for improvement lies in the reliance on qualitative analysis based on discursive transcripts. Although this approach provides detailed insight into semantic dynamics, it may also introduce interpretive biases that could influence the results. Future studies could address these limitations through comparative analyses across different scientific disciplines or educational levels.[4,5] Furthermore, it would be valuable to explore how cultural and institutional variations affect the practical application of the LCT theoretical framework.

Key contributions

This work highlights how strategic transitions between GS+ and GS can convey complex scientific concepts in the classroom. By providing a replicable model based on semantic profiles, this study not only validates previous research on LCT and GS but also offers practical tools to improve pedagogical strategies in science. These contributions are particularly relevant for educators interested in optimizing conceptual learning through evidence-based approaches.

Furthermore, this study establishes a bridge between theory and practice by demonstrating how the abstract principles of LCT can be directly applied in real educational settings. This not only facilitates a deeper understanding of the theoretical framework but also empowers teachers to design more effective lessons that respond to the specific needs of their students. Ultimately, this work advances theoretical and practical knowledge on how scientific knowledge is constructed and communicated in the classroom.

Final considerations

Semantic gravity was used in this study to analyze how a chemistry teacher transitioned between contextualization and abstraction when constructing definitions of "substance" and "solution" in a secondary school setting. The teacher's discourse revealed strategic shifts between concrete examples and abstract definitions, evidenced by moves defined by changes in GS intensity. For example, when defining "solution," the teacher initially employed strong semantic gravity by demonstrating the mixing of water and alcohol—a practical illustration that students can directly observe. Later, the teacher weakened semantic gravity by explaining solvent-solute relationships theoretically, encouraging students to conceptualize solutions beyond immediate sensory experiences.

The findings of this study highlight the importance of consciously managing variations in semantic gravity during lessons to optimize conceptual learning. By balancing concrete contexts and theoretical abstractions, teachers can effectively guide students from tangible experiences to more abstract and generalized understandings, thereby contributing to developing critical skills in science education.

Analysis of classroom discourse interactions showed that the teacher employed effective transitions between different levels of GS, starting with concrete examples and moving towards more abstract definitions. However, these transitions were not explicitly planned as part of a conscious teaching practice. This suggests that teacher education programs could significantly benefit from incorporating the semantic dimension of LCT to help future educators develop a reflective practice that consciously integrates these semantic variations into their teaching.[4]

Integrating GS into teacher training would allow educators to plan their lessons strategically, using semantic profiles to guide students from concrete experiences to abstract understandings. This would not only enhance the effectiveness of conceptual learning but also empower teachers to create more dynamic and adaptive learning environments. For example, when planning a lesson on chemical solutions, a teacher could consciously structure the class, to begin with practical experiments (GS+), then introduce molecular theories (GS-), and finally return to practical applications to consolidate learning.[11,18,19]

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Conflicts of interest

The author declares there is no conflict of interest.

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