Inorganic Compounds in the Environment. A Sequence of Teaching and Learning to Develop Critical Thinking in Tenth-Grade Students

- Compostos inorgânicos no meio ambiente. Uma sequência de ensino e aprendizagem para desenvolver o pensamento crítico em alunos da décima série
- Compuestos inorgánicos en el ambiente. Secuencia de enseñanza y aprendizaje (sea) para desarrollar pensamiento crítico en su aprendizaje

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Abstract

This article presents the results of a research carried out at the Liceo Fesán educational institution in Bogotá with tenth grade students, and was intended to relate the chemistry class curriculum with environmental education. Three phases were raised: the application of a pre–test, a Sequence of teaching and learning (SEA) and the application of a post–test. The test used was the Halpern test that allowed characterizing some of the critical thinking skills and a SEA was developed to strengthen the argumentative processes of tenth grade students in the learning of inorganic compounds and their impact on the environment through the development of critical thinking skills. This research is carried out in relation to axes one and two of the CyTPENCRI project, in which didactic instruments are applied to develop critical thinking and argumentation. It is concluded that the didactic intervention does promote a change in critical thinking skills and a relationship between environmental education and the chemistry curriculum.

Keywords

learning; inorganic compound; teaching; environment; critical thinking skills; chemistry

Resumo

Este artigo apresenta os resultados da pesquisa realizada na instituição educacional Liceo Fesán de Bogotá, com alunos da décima série, e teve como objetivo relacionar o currículo das aulas de química com a educação ambiental. Foram levantadas três fases, a aplicação de um pré-teste, uma sequência de ensino e aprendizagem (aae) e a aplicação de um pós-teste. Foi utilizado

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o teste de Halpern, que permitiu caracterizar algumas das habilidades de pensamento crítico, e uma aae foi desenvolvida para fortalecer os processos argumentativos dos alunos da décima série na aprendizagem de compostos inorgânicos e seu impacto no meio ambiente através do desenvolvimento de habilidades de pensamento crítico. Esta pesquisa é realizada em relação aos eixos um e dois do projeto CYTPENCRI, no qual são aplicados instrumentos didáticos para o desenvolvimento de pensamento crítico e argumentação. Em conclusão a intervenção didática promove uma mudança nas habilidades de pensamento crítico e uma relação entre a educação ambiental e o currículo de química.

Palavras chave

aprendizagem; composto inorgânico; ensino; pensamento crítico; meio ambiente; química

Resumen

Este artículo presenta los resultados de una investigación realizada en la institución educativa Liceo Fesán de Bogotá con estudiantes de grado décimo que tuvo como propósito relacionar el currículo de la clase de Química con la educación ambiental. Se plantearon tres fases: la aplicación de un pretest, una Secuencia de Enseñanza y Aprendizaje (SEA) y la aplicación de un postest. Se utilizó el test de Halpern que permitió caracterizar algunas de las habilidades de pensamiento crítico y se elaboró una SEA para fortalecer los procesos argumentativos de los estudiantes de grado décimo en el aprendizaje de los compuestos inorgánicos y su impacto en el ambiente a través del desarrollo de competencias de pensamiento crítico. Esta investigación se desarrolla en relación con los ejes uno y dos del proyecto CYTPENCRI, en la cual se aplican instrumentos didácticos para desarrollar el pensamiento crítico y la argumentación. Se concluye que la intervención didáctica sí promueve un cambio en las habilidades de pensamiento crítico y una relación entre la educación ambiental y el currículo de química.

Palabras clave

aprendizaje; compuesto inorgánico; enseñanza; medio ambiente; pensamiento crítico; química

Introduction

The curricular contents for teaching Chemistry should focus on motivating students to understand the phenomena presented in their context and their relationship with the content (Melo, 2017; Amórtegui, Gavidia, and Mayoral, 2017; Rivas, Amórtegui, and Mosquera, 2017). According to Piñeros et al. (2014), "Chemistry teaching uses curricula based on a variety of topics related to the branches of this science but neglects their interests and motivations, very distant from their context." As a result, content and concepts have been transmitted over time without understanding their utility. Tamayo (2014) proposes that teachers play a fundamental role in the integral formation of students and in enhancing the development of critical thinking through the development of thinking skills.

Caamaño (2006) analyzes the current situation of Chemistry teaching, explaining how students fail because the contents of the sciences are detached from their real context, and it restricts teachers' ability to explore alternatives that promote science learning creatively.

In this research, pedagogical and didactic strategies have been implemented to strengthen teaching and learning processes, linking the learning of chemistry with students' everyday life and, in this specific case, with environmental education, generating an interest in their own learning and the value that can be attributed to it. In this regard, Caamaño (2011) proposes didactic sequences to provide content in a contextualized manner, focusing on the inquiry and debate of chemistry.

Vázquez et al. (2013) propose Teaching and Learning Sequences (TLS) as a strategy that involves a series of activities on the chosen theme, with particular attention to students' conceptions, allowing teachers to innovate in their pedagogical practice and captivate students in their discipline, specifically in learning chemistry and its relationship with environmental education.

During the application of TLS, critical thinking skills in students, such as hypothesis verification, analysis of arguments, problem-solving, and decision-making, can be strengthened through the appropriate use of activities and content proposed in the educational tool to achieve meaningful learning.

Based on the above, a question arises that guided the development of this research: How do we strengthen the argumentative processes of tenth-grade students in learning inorganic compounds and their impact on the environment through developing critical thinking competencies?

To address the problem, the general objective is to implement a Teaching and Learning Sequence (TLS) to strengthen the argumentative processes of tenth-grade students in learning inorganic compounds and their impact on the environment through developing critical thinking competencies.

As specific objectives of the research, the following are proposed: identify the critical thinking skills of students concerning argumentation, decision-making, and problem-solving using the Halpern test; design the TLS "The world of inorganic compounds in the environment," which is applied in the classroom with a group of tenth-grade students to foster argumentative processes based on environmental problems in the context, and evaluate how the TLS influences as a didactic intervention instrument in the development of critical thinking skills, for which the Halpern test is applied to students again.

Within the didactic innovation, this research promotes social appropriation based on

recognizing environmental problems and the importance of theoretical knowledge of chemistry through applying a TLS under an argumentative model that strengthens critical thinking skills.

Theoretical Framework

Critical Thinking Skills

Developing students' critical thinking skills has been a topic of great interest among researchers and educators (Scheid, 2016). Beltrán et al. (2009) assert that students do not demonstrate cognitive skills in teaching and learning processes, so their learning processes are low.

Various authors have defined critical thinking as reasoned and reflective thinking, a higher-order thinking that evaluates the results and the process of thinking (Nieto et al., 2008). Other authors like Solbes (2019) relate critical thinking to the ability to make rational choices and informed judgments as elements of the decisions used to solve problems. The assessment of critical thinking has focused on applying tests that have allowed categorizing skills through everyday situations, as is the case with the HCTAES and PENCRISAL.

According to Halpern (2006), five critical thinking skills can be characterized: verbal reasoning, argument analysis, hypothesis testing, probability and uncertainty, decision-making, and problem-solving.

For Halpern (2016), the skill of verbal reasoning is the reciprocal relationship between language and thought, that is, the language used to express thoughts. For other authors like Morales et al. (2017), this reasoning can be deductive when evaluating propositional and categorical reasoning; inductive, using analogical and hypothetical reasoning when working from inductive generalizations; and practical, which assesses argumentation and the evaluation of fallacies in knowledge.

The skill of argument analysis is a set of statements with a conclusion and a reason (Halpern, 2016), where the stated conclusion is coherent with the argument itself. Ocampo et al. (2017) define argumentation as how students learn to defend their position on a topic, phenomenon, or reality and become protagonists of their knowledge. In the science class, argumentation allows students to develop cognitive, social, and emotional skills (Ocampo et al., 2017).

Hypotheses are recognized as preliminary ideas that explain a fact or a problem, and these hypotheses must be tested and verified to check the arguments with which the hypothesis has been generated (Beltrán et al., 2009). Similarly, hypotheses can stem from initial qualitative analyses of a problematic situation and continue with their formalization into a model, which allows for explaining

phenomena, predicting events, or projecting the control of specific processes in reality (Valdés et al., 2004; Vizcaino and Terrazzan, 2015).

The skill of probability and uncertainty allows for the quantitative determination of the possibility of analyzing an event. According to Beltrán et al. (2009), when this skill is employed, it enables decision-making by analyzing and assessing alternative solutions and considering the advantages and disadvantages that may arise when making decisions or solving the presented problem.

Halpern (2016) indicates that all critical thinking skills are used in decision-making and problem-solving. This skill proposes recognizing and defining problems with relevant information, contrasting possible solutions, and acknowledging that these alternatives should consider positive and negative outcomes.

Teaching and Learning Sequences (TLS)

The design of teaching and learning sequences should creatively integrate concepts, themes, and knowledge that are challenging for students to learn (Furió et al., 2012). It is a strategy that facilitates the teaching of specific areas of knowledge.

Meheut et al. (2004, cited in Zenteno et al., 2010) define them as activities or instructional approaches inspired by educational research to help students understand scientific knowledge. It is also proposed that using these strategies promotes and strengthens argumentative processes in students. Sequences should be oriented towards learning specific content, which has specific characteristics framing conceptual and curricular aspects, as Pérez et al. (2017) suggested. In developing this pedagogical and didactic tool, factors such as grade, age, and the contents to be addressed according to the curriculum should be considered.

Callejas et al. (2015) propose teaching and learning sequences (TLS) as an instrument for didactically planning curricular interventions. The development of TLS involves teachers engaging in reflective planning, including justification, objectives, conceptual structure, educational context, activities, materials, and evaluation. These sequences should be applied in the classroom to enhance the learning of the nature of science and technology.

Chemistry Education

As an essential and fundamental science within the educational curriculum, chemistry education has historically led to the transmission of content mediated by ambiguous formalisms that lack a connection to society and the students' immediate context.

For some students, becoming familiar with chemical language is challenging, as Valero et al. (2009) suggested: "They find it difficult to learn and retain. They cannot clearly understand how chemical elements combine, the meaning of valence, oxidation numbers, and IUPAC nomenclature." Consequently, many students resort to rote memorization, leading to difficulty in learning chemistry.

It is necessary to analyze and seek strategies that motivate students to learn chemistry by contextualizing the current curriculum. According to Piñeros et al. (2014), "There is an urgent need to rethink what is taught, how it is taught, and why it is taught. Designing a curriculum that presents contents and themes that genuinely interest students is essential".

Chemistry, as part of the curriculum in the Natural Sciences, aims to transform the perception of nature. However, it has become complex and tedious for students

because the applicability of the concepts studied is unclear. This is a current issue in education (Ortega and Perafán, 2016).

Inorganic Chemistry and Pollution

Various research studies have demonstrated that certain inorganic compounds impact the environment and disrupt ecosystems, such as certain metals and anions (nitrates and cyanides), which can be toxic to humans and organisms. Additionally, most of these compounds cannot be easily degraded. Alguacil et al. (1998) explain that metals are essential for human life, plants, and microorganisms as they serve as nutrients. However, when they exceed safe limits, they can become toxic and are considered pollutants, turning soil, water, and air into hazardous ecosystems for humans and ecological processes.

Sulfur compounds, like sulfur dioxide originating from fixed sources like fossil fuel combustion and oil refineries, form sulfuric acid upon contact with atmospheric water. This acid remains suspended in the atmosphere, negatively impacting health and causing respiratory irritation in humans (Marchetti, 2010). During the combustion of fossil fuels (coal and oil), nitrogen compounds oxidize, forming nitrogen monoxide and dioxide, leading to health repercussions such as respiratory and cardiac diseases.

On the other hand, Fernandez (2010) determines that soil pollution arises from chemical or biological alterations incompatible with its functions, including inorganic compounds such as metals and non-metallic minerals from mining industries, causing soil changes and nutrient reduction.

The reduction of freshwater is reflected by the high pollution from industrial, chemical, and domestic effluents, fertilizers, and pesticides. Inorganic contaminants like arsenic, cadmium, nitrates, and lead are found in higher concentrations and affect aquatic ecosystems (Gait et al., 2010).

Evaluation of Critical Thinking

Various tests and assessment tools have been created to develop relevant tools for assessing critical thinking skills. Mendoza (2015) compiles different tests that address the evaluation of critical thinking from a quantitative perspective, such as the Watson-Glaser Test (WGCTA), Cornell Test (CCTT), Ennis-Weir Test, California Test (CCTSI), Halpern Critical Thinking Assessment Using Everyday Situations (HCTAES), Sternberg's Questionnaire, Pencrisal Test, and Critical Thinking Questionnaire CPC 2. Among these, the Pencrisal and HCTAES tests are highlighted as valuable and innovative tools, emphasizing the latter's relevance (Halpern Test) for assessing specific skills such as decision-making, problem-solving, and deductive and inductive reasoning.

Methodology

The present research was conducted under a quasi-experimental approach, utilizing qualitative data collection in three phases: in the first phase, critical thinking skills were characterized using the HCTAES test (pretest); in the second phase, the SEA "The world of inorganic compounds in the environment" was implemented, and in the third phase, critical thinking skills were evaluated using the HCTAES test (posttest).

Population

A total of 28 tenth-grade students, aged between 15 and 16, from Liceo Fesán school participated in the research. The school offers two emphases: one focused on business management and the other on science and technology, which students choose to pursue during their two years of vocational education.

Instruments

Pretest

The Halpern test was administered to characterize some critical thinking skills. According to Beltrán et al. (2009), formulating hypotheses and strategies promotes arguments that support learning construction. The test assesses these skills by presenting everyday situations.

The Halpern test consists of twenty-five everyday situations using a dual-question format. The first open-ended question allows students to provide arguments or express their opinions on the presented situation. The second question is closed-ended, requiring students to choose an option or explain the situation. Seven situations were selected from the test, evaluating decision-making, problem-solving, and argument analysis skills.

Teaching-Learning Sequence (TLS)

A TLS named "The world of inorganic compounds in the environment" is designed to bring students closer to understanding the study of inorganic compounds and their relationship with the environment.

Within the TLS, a critical, reflective, and structured analysis of the acquired knowledge is proposed, emphasizing the connection of these contents with their immediate surroundings. Students are made aware of the environmental changes caused by using many products available in the market and industry, in which they actively participate in their daily lives. The focus is on identifying how inorganic compounds, due to their structures, alter and impact the environment.

This sequence is designed to achieve the following objectives and is implemented over six sessions:

- Facilitate spaces for debate and analysis of environmental issues arising from using inorganic compounds.
- Argue about the structure of inorganic compounds and their everyday use.
- Recognize inorganic functions and functional groups to determine their environmental impact.
- Encourage explanations of the learned topics and their applicability.

This sequence has been developed under the didactic structure proposed by Eisenkraft (in Vázquez et al., 2013) called the "7E Learning Cycle," consisting of stages that begin with the letter E (Engage, Elicit, Explore, Explain, Elaborate, Extend, and Evaluate) (Table 1).

Table 1. *TLS, according to the EANCYT project model*

Title: The World of Inorganic Compounds in the Environment	**Number of sessions:**	**Six**
Justification/General Description These activities aim to bring students closer to the understanding of the study of inorganic compounds, focusing on the implementation of these compounds, their structure, and how they impact the environment. It is crucial for tenth-grade students to relate the topics covered to their immediate surroundings and to apply their learning through critical, reflective, and structured analysis. They should be aware of the environmental changes caused by using various products in the market and industry in which they actively participate. The goal is for students to identify how inorganic compounds, through their structures, alter and affect the environment.	Level/Phase	High School (15-16 years old)
	Grade	Tenth
Relation to the Curriculum	**Subject**	**Chemistry**
The design and implementation of a didactic strategy involve recognizing inorganic compounds, the types of reactions leading to their formation, balancing reactions, and understanding how using some compounds impacts the environment.	Block	Inorganic Chemistry
Basic Competency(ies): Scientific Competence		
Scientific explanation, communication of information, proposing possible explanations, logical reasoning, interpretation, and argumentation.		
Objectives		
• Foster spaces for debate and analysis of environmental issues by using inorganic compounds. • Argue about the structure of inorganic compounds and their everyday use. • Recognize inorganic functions and functional groups to determine their environmental impact. • Encourage explanations of learned topics and their applicability.		

Time	**Activities (Students/Teachers)**	**Methodology**	**Materials/ Resources**
60 minutes	Engage, Introduction-Motivation Based on the videos, reflection occurs regarding the indiscriminate use of inorganic compounds and how they alter the environment. After watching the videos, students will choose an image from those available on the board. They will then paste the chosen image onto a sheet of paper and write a paragraph connecting the selected image to one of the videos.	Whole class organization Individual writing	Videos and pictures, board
60 minutes	Elicit prior knowledge Students respond in writing to the questions: What are inorganic compounds? What compounds are present in the household cleaning products you use? Have you considered environmental care? What is the environment? Then, they share their responses in groups and engage in an activity with everyday use products.	Whole class organization Individual writing Activity	Verbal Written Products (toiletries, medication, beauty care products)
Developing activities			
60 minutes	Explain content The proposal involves working with a reading that identifies a significant environmental impact resulting from the excessive use of household products. This reading will include the structures and some formulas of inorganic compounds to integrate disciplinary knowledge with environmental impacts. Following the reading, there will be a series of questions for groups to solve, leading to subsequent group discussion and explanation by the teacher.	Groups of 3 people	Reading

Title: The World of Inorganic Compounds in the Environment		Number of sessions	Six
60 minutes	Explain procedures Starting from an environmental impact caused by a chemical reaction, students will present the procedure (Formation of compound, types of compounds, and balancing) and discuss why pollution occurs, constructing group arguments (They are asked to use the MAT).	Groups of 3 people	Impact and chemical reactions Oral and written
40 minutes	Explore Consolidation At the end of the activity, the teacher compiles the information and provides feedback on each topic covered, emphasizing the importance of the knowledge acquired in inorganic chemistry and its impact on the environment.		Oral and written
Assess			
30 minutes	Halpern Test Questions	Pre-post test	HCTAES
	Criteria/Indicators		
	Social Strengthening		
	Extend reinforcement activities		
	Extend recovery activities		
	Extend expansion activities		
	Explanation of the environmental impacts that have been caused by the improper use of products that have been made with inorganic compounds	Class groups	Videos and verbal

Source: own elaboration

Postests

Completed the implementation of the TLS, we waited for a month to reapply the Halpern test with the seven everyday situations selected for the *pretest*. The change in the closed responses of each student is evaluated, analyzing thinking skills as proposed by the CyTPENCRI project, thus assessing the impact of the SEA on teaching and learning processes.

Results

First Phase: Characterization of Critical Thinking Skills

The results of the closed questions are presented, which are systematized through the tabulation proposed in the Halpern manual. According to the manual, by having the examiners choose a response option, they would be able to recognize the proper use of critical thinking skills. Meanwhile, open or constructed responses allow the analysis of critical thinking skills (Halpern, 2016).

Hypothesis Testing (S1, parts 1 and 2)

The existence, relevance, and appropriateness of arguments supporting hypotheses related to an issue show success in only 25%, and the choices of justifications necessary to support the hypotheses, selected in the first part, present a 21% correct response rate. These results indicate that most of the group is below the minimum threshold of 25%, meaning their critical thinking skills are weak or not yet developed. In this way, their overall, passive, or active applications are only superficial.

Analysis of Arguments (S12, S13, and S15)

The search for conclusions considering supporting reasons or flaws and the search for reasons and recognizing differences between

assumptions and conclusions shows an average success rate of 48.7%. This indicates that the group mainly falls within the average, meaning they eventually establish differences between unconscious opinions and reasoned thinking. Through training processes, they would be susceptible to strengthening their analyses.

Decision-Making and Problem-Solving (S21, S23, and S24)

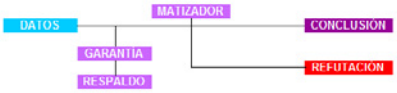
Identifying relationships between possible factors associated with an issue implies using critical thinking skills in decision-making processes, yielding a success rate of 32.21%. This suggests that participating students partially and infrequently select resolution alternatives based on relevant criteria. Therefore, their resolution does not show movement between the starting area and the proposed objectives, meaning the selection of options is frequently deficient.

Second Phase: Implementation of the TLS

The second phase highlights the activities of the TLS, corresponding to the six class sessions (Table 2).

Table 2. *SEA Activities for the 6 Class Sessions*

Stage	Activity-description	Observation
Hook-Engage	For this activity, 60 minutes are allocated, and the session is divided into two parts. In the first part, students are shown videos about the indiscriminate use of products in industry and personal and household hygiene. These products contain some inorganic compounds, such as strong acids or bases, that contaminate the environment. In the second part, images of products are displayed on the board, each student selects an image, creating a paragraph explaining why they chose that image and its relationship with the previous. watched videos or their daily lives.	There is a favorable disposition among students toward the addressed topic in the videos, generating an understanding of some environmental impacts (e.g., contamination of the Bogotá River) due to industrial waste and household waste deposited in landfills. For the image selection, students express that they choose the image of the product they have the most contact with in their daily activities or the ones their mothers use most frequently for household cleaning.
Elicit	A series of questions are planned for students, which they must answer on a sheet: What are inorganic compounds? What compounds do the cleaning supplies used at home have? Have you thought about environmental care? What is the environment? They have 30 minutes to answer and then share their responses in the group. Each student must bring the label of a cleaning or medicinal product frequently used at home for this session to describe its production and use.	Students individually answer the questions on a sheet, with some showing interest in the activity by relating their responses to their daily actions, acknowledging their lack of concern for environmental issues. In groups, they share the label of the product they brought and begin to analyze what inorganic compounds it contains and how they, due to their structure, can affect the environment if not used with caution or used indiscriminately.
Explain (Contents)	Working with readings where environmental impacts due to the excessive use of chemical products based on inorganic compounds are identified. Each student is tasked with presenting a reading that caught their attention due to its environmental impact.	Each student brings a reading to class, forming groups of 3 or 4 people. A preliminary reading of each is conducted, and one is chosen. With it, they must explain the environmental problem, what caused it, and what products are involved, and create a problem tree or diagram to share the importance of their reading with other groups. They must show why that chemical product generates an environmental impact (noting its chemical compound).

Stage	Activity-description	Observation
Explain (Procedures)	They will choose a chemical reaction that has caused an environmental impact and must explain the procedure (formation, types of compounds, balancing, nomenclature). They will also explain why pollution occurs (using the MAT).	From the previous activity, they chose an inorganic chemical compound that has affected the environment due to its reaction. They write the compound and its structural and molecular formula; on a poster, they write the compound and the reactions that occur with agents like water, among others. This way, they explain how that compound altered the environment using the MAT. Scheme of MAT  Source: G3 G4 CyTPENCRI argumentation guide
Explore (Consolidation)	The teacher compiles the worked information and provides feedback on the topics.	During the consolidation session, students willingly explain the activities and the product obtained from each. A discussion takes place where each participant explains how the proposed curriculum topics were learned differently, not mechanically, generating a more significant impact on their learning.
Extend	Explanation and discussion about the environmental impacts of the inappropriate use of inorganic compounds in producing many industrial products.	A final closing activity is carried out where each student shows their strength in what they have learned about inorganic chemistry through an example and the care that must be given to the environment. They acknowledge that they are a generation that neglects the environment and the country's situation due to the indiscriminate use of products and resources.

Source: own elaboration

Based on the results obtained, a matrix is designed to characterize the levels of argumentation of tenth-grade students regarding each proposed TLS activity. For this matrix, four levels of argumentation are taken into account, and for each of them, an analysis criterion is developed, which is elaborated considering the MAT, as follows (Table 3).

Table 3. *Matrix for the analysis of the TLS according to the MAT*

Argumentation level	Analysis Criteria
One	There are no clear reasons supporting the analyzed process, and the activities lack exposition.
Two	There are no clear reasons supporting the analyzed process, and the activities lack exposition.
Three	The reasons explaining the analyzed process are clear and based on backing; however, there are some difficulties in identifying certain relationships between inorganic compounds, their structure, and the contamination process.
Four	The reasons explaining the analyzed process are clear, based on backing, and the argumentative discourse is coherent and structured, avoiding everyday language.

Source: own elaboration

Upon reviewing the texts developed by the students, levels of argumentation can be identified within levels one to three, according to the SEA analysis matrix. In the first level, the presented ideas lack support, assurances, or evidence to underpin the claims. In most of these cases, they assume that the presented cleaning and personal hygiene products cause environmental impacts due to their chemical composition but do not provide support for this (Figure 1).

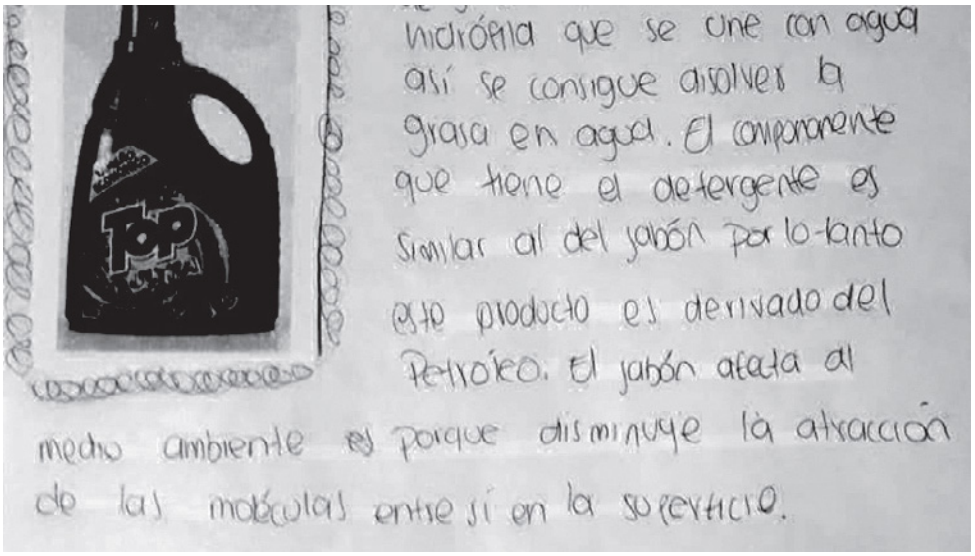


Figure 1. *Student's text at the initial phase of the TLS, level 1*

Source: own elaboration.

At level 2, there is a basic inclusion of evidence, where students tend to use them as the sole support to reach a conclusion without considering other categories. Thus, when examining the texts, one can identify information obtained from videos related to the topic, as well as basic support regarding the compounds involved in the production of the analyzed products. They present the compounds in more detail and mention them in some cases (figures 2 and 3).

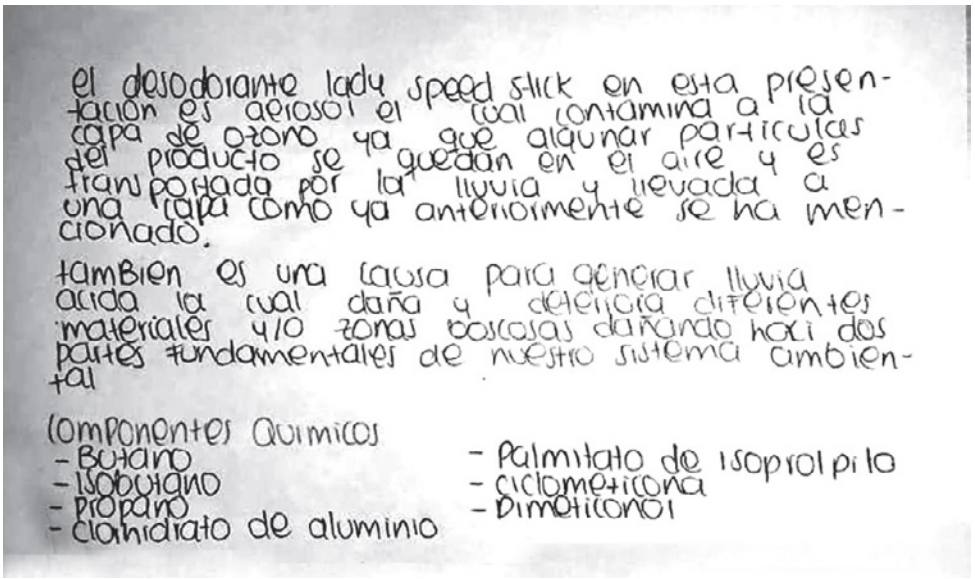


Figure 2. *Student's text at the initial phase of the TLS, level 2*

Source: own elaboration.

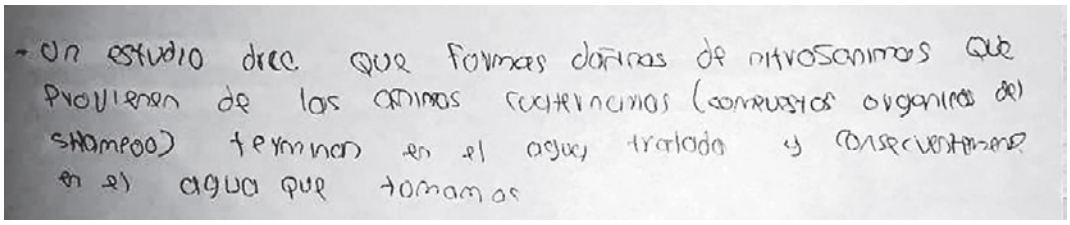


Figure 3. *Student's text at the initial phase of the TLS, level 2*

Source: own elaboration.

Regarding level 3, the evidence presented by the students improved compared to those identified in levels 1 and 2, both in quantity and quality. In general, the data provided by them emphasize the environmental consequences of the chemical compounds used in the production of the analyzed products. However, in the initial argumentation process, there is a tendency to incorporate general ideas. According to Manassero et al. (2020), this tends to be low-quality and faulty thinking associated with experience in using the mentioned products and their prior ideas (figures 4 and 5).

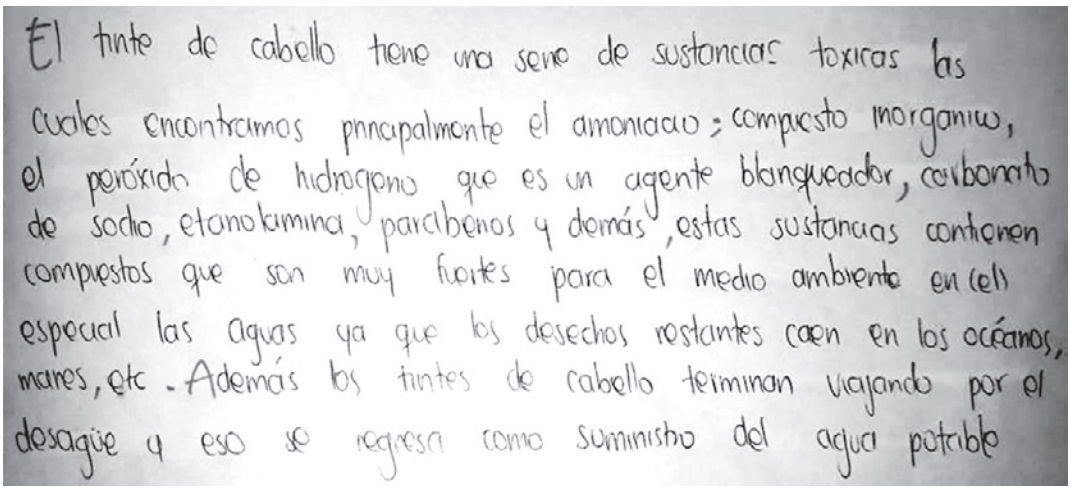


Figure 4. *Student's text at the initial phase of the TLS, level 3*

Source: own elaboration.

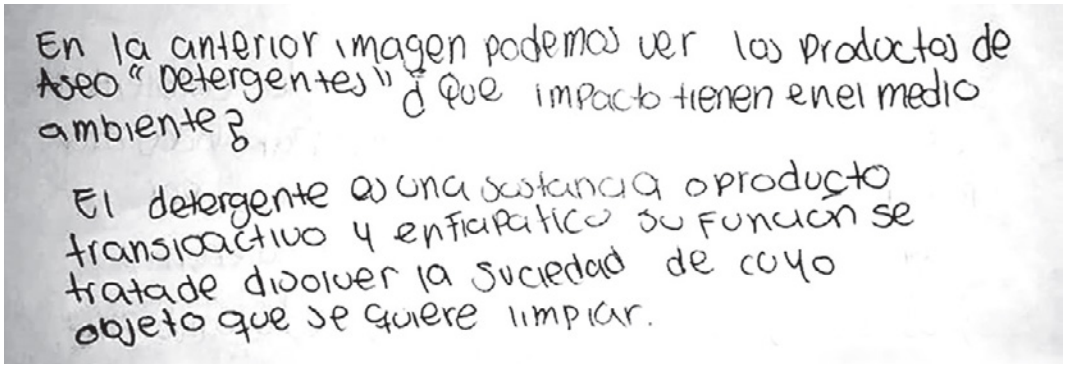


Figure 5. *Student's text at the initial phase of the TLS, level 3*

Source: own elaboration.

For the evaluation of the SEA and the knowledge acquired by the tenth-grade students, the questionnaire proposed by the CyTPENCRI project was applied, identifying whether what was learned in the SEA was interesting, if it helped them become more critical, and if it helped them acquire scientific competencies (Figure 6).

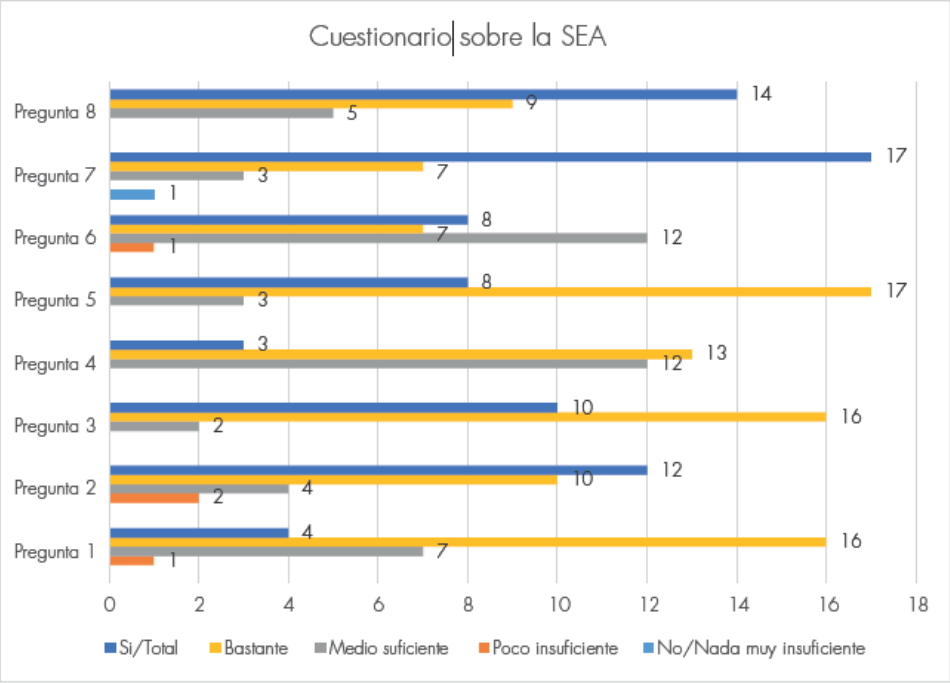


Figure 6. *Questionnaire ot tls CyTPENCRI*

Source: own elaboration.

Within the interview conducted to evaluate the TLS, the students determine that it has been quite interesting, using statements such as "learning inorganic chemistry has been easier, and what was learned during classes is more useful"; "it is another way to acquire knowledge and relate environmental issues, such as pollution caused by some chemical compounds (nitrogen, sulfates, among others)."

In question three of the interview, they are asked what aspects they consider most relevant and why it is very relevant. They respond that some crucial aspects are the news they had to search for to relate disciplinary knowledge to some of the global environmental contaminations. This allowed them to acquire arguments and reasons for many phenomena seen daily or to reinforce arguments to refute with their peers about environmental issues. An example of this is the fact that students chose news such as "When the river sounds, Nitrate carries: The poison that the Spanish drink," where they identify that this water pollution is due to the indiscriminate use of fertilizers and pesticides, leading nitrates to bodies of water.

Third Phase. Evaluation of Critical Thinking Skills

The analysis of responses to the posttest is based on the proposed categories and according to the critical thinking skills evaluated in the Halpern test, maintaining the selection and evaluation only of part two of each situation.

Verification of Hypotheses (S1, parts 1 and 2)

In this part of the test, the recognition of the elements that underlie and support the hypotheses presented shows significant progress by the group of students, increasing from 25% to 53.57%. The choices of justifications necessary to support the hypotheses selected in the first part show an increase of 18.28% in correct answers, going from 21% to 39.28% (Figure 7). Regarding this skill, there is a noticeable increase in the use of facts and sensible reasoning as support tools, as indicated by Paul et al. (2005, p. 24). These results indicate that most of the group achieved a significant improvement in developing their hypothesis verification ability, identifying a more significant presence of components of global application, as these effectively integrate conclusions and students' prior knowledge (Figure 8).

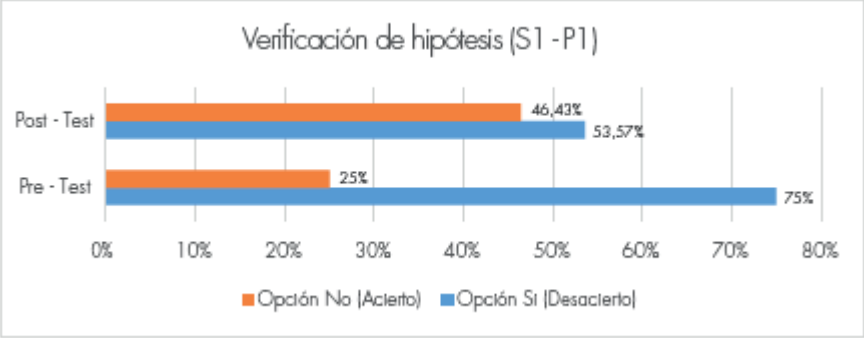


Figure 7. *Hypothesis Verification (Situation 1-Part 1)*

Source: Own elaboration.

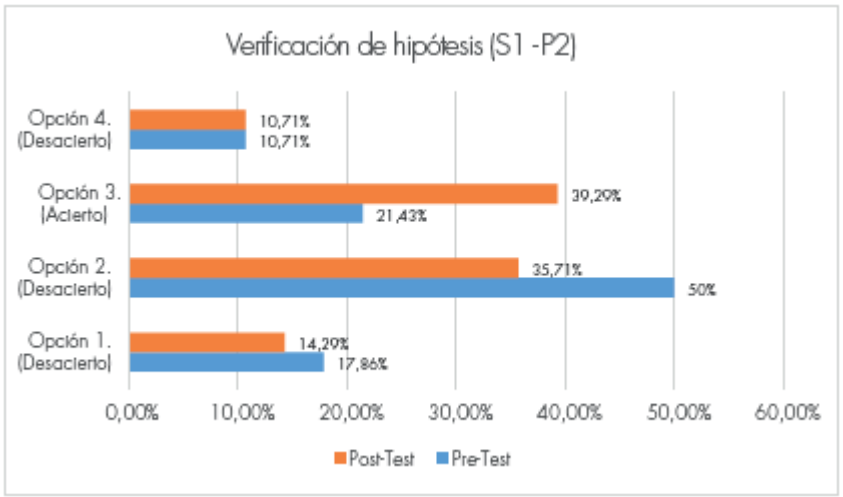


Figure 8. *Hypothesis Verification (Situation 1-Part 2)*

Source: Own elaboration.

Analysis of Arguments (S12, S13, and S15)

There is a slight improvement in actions aimed at seeking conclusions, where students identify elements causing intervention in an argument with a slight advance. There is still a partial recognition of differences between assumptions and conclusions, presenting an average accuracy rate of 54.21%. Compared to the pretest results (48.7%), this maintains the initial trend (Figures 9, 10, and 11). This indicates that there is still an occasional identification of differences between unconscious opinions and reasoned thinking. Regarding the development of argument analysis skills, the tls provided spaces where students could identify reasons, conclusions, and counterarguments in debates on simple issues. Gradually, more complex topics are addressed, facilitating not only instant improvements but also persistence over time. This approach aligns with the strategy mentioned by Casallas et al. (2018) for strengthening this skill.

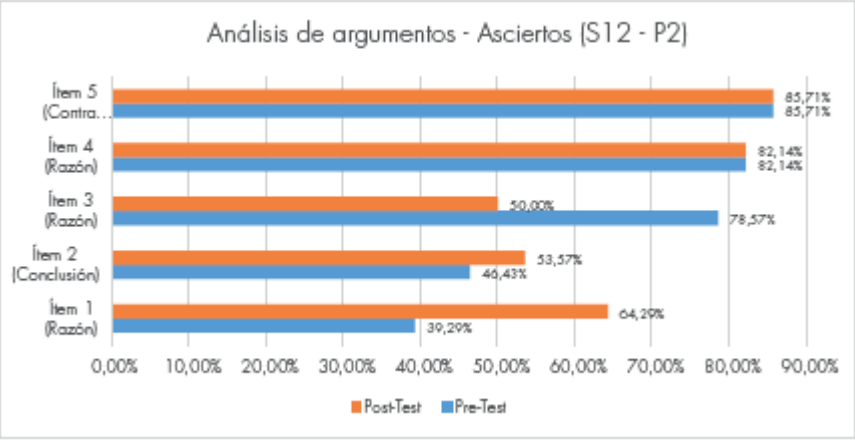


Figure 9. *Skill Analysis of Arguments Accuracy (Situation 12-Part 2)*

Source: Own elaboration.

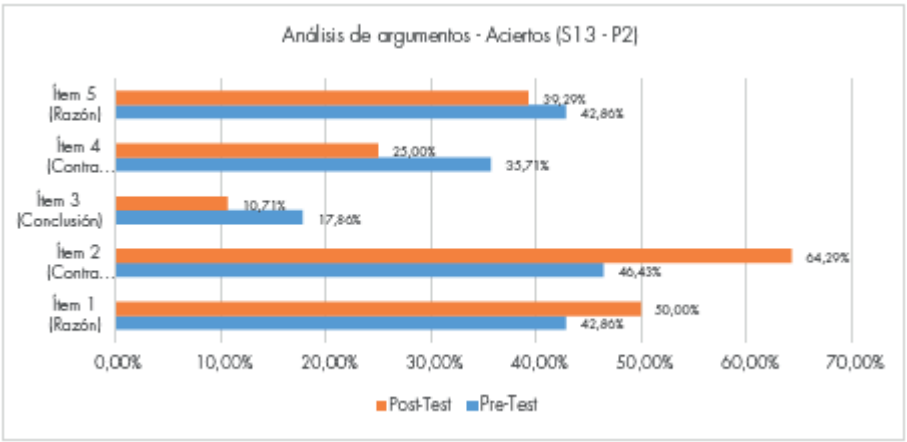


Figure 10. *Skill Analysis of Arguments Accuracy (Situation 13-Part 2)*

Source: Own elaboration.

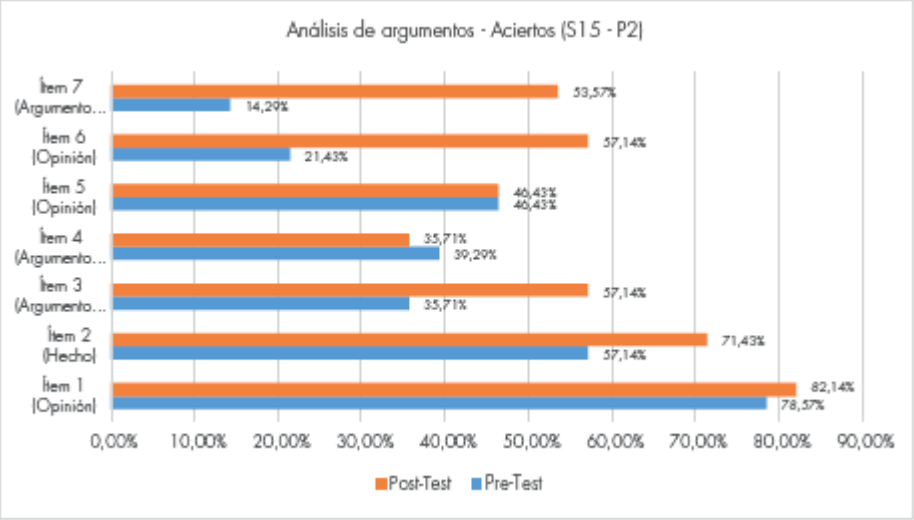


Figure 11. *Skill Analysis of Arguments Accuracy (Situation 15-Part 2)*

Source: Own elaboration.

Decision-Making and Problem-Solving (S21, S23, and S24)

The results indicate an effectiveness percentage of 45.19%, suggesting that the use of critical thinking skills was more frequent in decision-making, with an increase of 12.98% from the pretest accuracy of 32.21%. This indicates that participating students choose resolution alternatives based on relevant criteria more effectively, showing movement between the starting area and the proposed objectives. In other words, the selection of options has ceased to be frequently deficient (Figure 12).

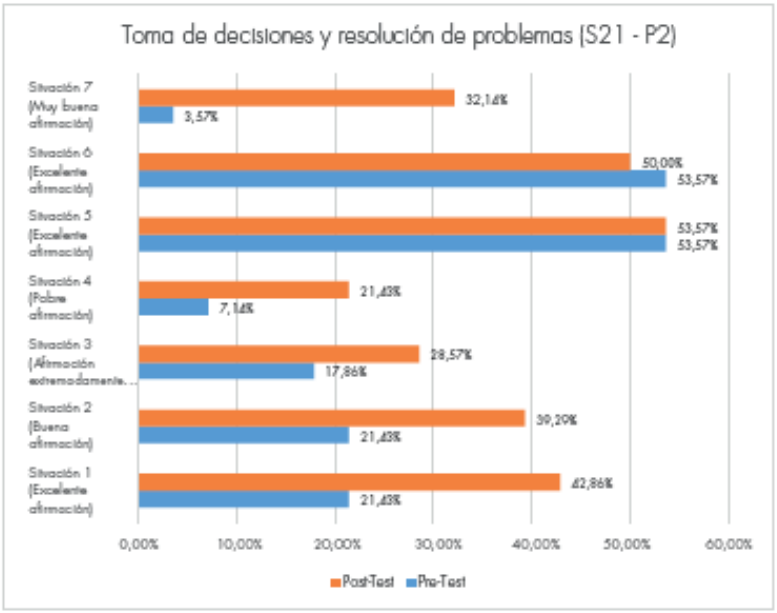


Figure 12. *Skill Accuracy in Decision-Making and Problem-Solving (Situation 21-Part 2)*

Source: Own elaboration.

Similarly, using situations from the context associated with the impact of inorganic compounds in everyday products generated a tendency to produce diverse responses, which in many cases were justified with valid reasons, facilitating a better understanding of chemical processes and phenomena. These understandings were achieved due to problem-solving strategies, serving as eliciting elements for critical thinking. In Figure 13, you can observe how this change occurred, from which a better consolidation in similar processes within the school, student, and family context can be expected.

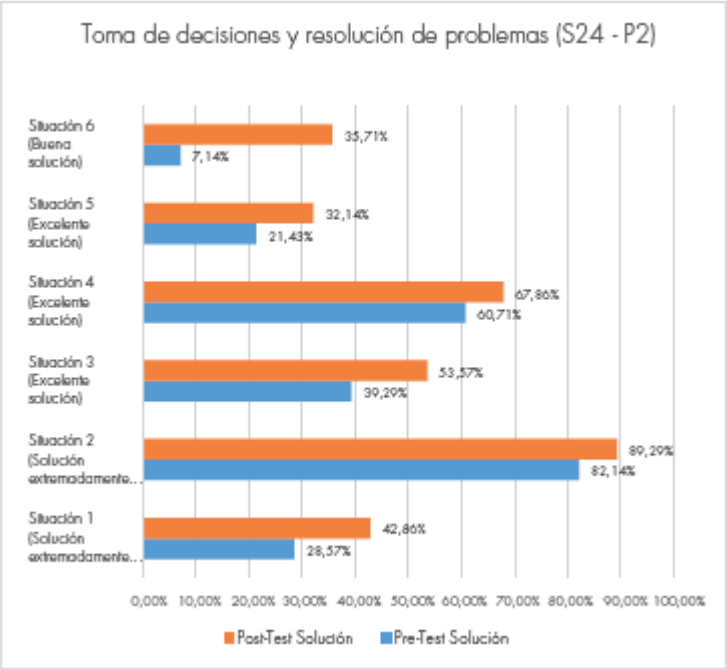


Figure 13. *Skill Accuracy in Decision-Making and Problem-Solving (Situation 24–Part 2)*

Source: Own elaboration.

Discussion of Results

According to the results obtained in this research, it can be asserted that implementing TLS can be a tool for strengthening critical thinking skills during the analysis and contextualization of environmental issues involving students. Additionally, based on the results obtained in the pretest and posttest using the Halpern test, scales for assessing critical thinking skills developed through the interaction between scientific knowledge learning and its application in everyday settings can be obtained. These can be characterized by the situations and evaluation components of the mentioned tool.

On the other hand, critical thinking skills can be strengthened primarily according to the identified needs after the test application, establishing connections with the phases oriented to them. The results allow for evaluating how each phase of TLS impacted strengthening critical thinking skills. Although the analysis situations

were the same, the percentage improvements in effectiveness can be more closely associated with contextualization and solving everyday problems. The use of environmental problems associated with the production and mass use of inorganic chemical products motivated most students to recognize how to apply scientific and technical knowledge to establish reasoned positions on the subject through argument construction and conclusion formulation.

Conclusions

With the approach to each of the situations presented in both the test and TLS, the level of development of skills increased, reflecting an immediate relationship between the knowledge acquired in the curriculum and relevant didactic intervention, supported by the use of tests that guide teaching actions in a pinpointed manner. It is very relevant to observe how the deficiencies in applying skills associated with the first presented situations decreased as students increased their ability to construct arguments.

The characteristics of the interaction between the test results and the activities proposed for TLS became an instrument for students to strengthen their critical thinking skills, turning the information initially approached superficially into knowledge that led to decision-making based on reasoned arguments. These were reflected in the proposed resolutions in both the Halpern test and TLS.

Throughout their education, tenth-grade students have participated in situations involving taking positions on a topic and drawing conclusions. Still, at the beginning of the research, these processes were not reflected in developing critical thinking skills in the pretest situations. With the processes of hypothesis verification, argument analysis, decision-making, and problem-solving associated with the activities proposed in SEA, students were able to express their arguments more easily, involving not only conventional verbal or written expression but also the use of images, diagrams, and charts to express connections between phenomena and arguments.

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