Argumentation's Development of High School Students from Nature of Science and Technology Approach

- Desenvolvimento da capacidade argumentativa em alunos do ensino médio a partir da perspectiva da natureza da ciência e tecnologia
- Desarrollo de la habilidad argumentativa en estudiantes de educación media desde el enfoque de la Naturaleza de la Ciencia y la Tecnología

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Abstract

The purpose of this research article is to contribute to the processes of scientific education of middle school students based on the development of argumentative ability, considering studies about physical principles. The argumentative skills addressed a learning sequence (ls), integrated into the sts approach, have proved the importance of a contextualized didactic process that encourages learning of fundamental aspects of the Nature of Science (NoS), particularly those opinions of students regarding external sociology of Science and Technology. The process evaluation, a quasi-experimental research design (pretest-ls-posttest), allowed us to recognize an improvement in the student's argumentative ability and their progress about Science and Technology. Thus, results show significant changes in students answers to specific situations in Halpern test and Opinion Questionnaire on Science and Technology.

Keywords

argumentative skill; critical thinking; science; technology; teaching; learning

Resumo

O objetivo deste artigo de pesquisa é contribuir para os processos de educação científica de alunos do ensino médio, com base no desenvolvimento da capacidade argumentativa, tomando como referência o estudo de alguns princípios físicos. As habilidades argumentativas abordadas em uma sequência de aprendizagem (sea), que integra a abordagem cts, evidenciaram a importância de um tratamento didático contextualizado com o qual incentivar a aprendizagem de alguns aspectos fundamentais da natureza da ciência (NdC), particularmente as opiniões dos alunos sobre questões que envolvem a sociologia externa da

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ciência e da tecnologia. A avaliação do processo, que segue um desenho de pesquisa quase experimental (pré-teste sea-pós-teste), permitiu reconhecer uma melhoria na capacidade argumentativa dos alunos e um progresso em relação à imagem da ciência e da tecnologia, que ratifica com mudanças significativas nas respostas dos alunos a algumas situações específicas do teste de Halpern e do Questionário de Opinião sobre Ciência e Tecnologia.

Palavras chave

habilidade argumentativa; pensamento crítico; ciência; tecnologia; ensino; aprendizagem

Resumen

El propósito de este artículo de investigación es contribuir a los procesos de formación científica de estudiantes de enseñanza media a partir del desarrollo de la habilidad argumentativa, tomando algunos principios físicos como eje de referencia. Las habilidades argumentativas abordadas en una secuencia de aprendizaje (sea) —que integra el enfoque cts— evidencian la importancia de un proceso didáctico contextualizado que fomente el aprendizaje de aspectos fundamentales de la Naturaleza de la Ciencia (NdC); particularmente, las opiniones que formulan los estudiantes frente a cuestiones que involucran la sociología externa de la ciencia y la tecnología. Con la evaluación del proceso con un diseño de investigación cuasiexperimental —pretest-sea-postest—, se reconoció una mejora en la habilidad argumentativa de los estudiantes y su progreso respecto a la Ciencia y la Tecnología. Así, se ratifican algunas situaciones específicas gracias a cambios significativos en las respuestas de los estudiantes en el Test de Halpern y el Cuestionario de Opiniones sobre Ciencia y Tecnología.

Palabras clave

habilidad argumentativa; pensamiento crítico; ciencia; tecnología; enseñanza; aprendizaje

Introduction

The accelerated growth of the world population—7.7 billion people by the end of the second decade of the 21st century (UN, 2019)—and the increased use of mobile devices by 66% of the global population (GSMA, 2019) reveal the complexity in the processes of selection and social appropriation of information circulating on the internet. Some research indicates that more authors subject their articles to public scrutiny through alternative metrics (Altmetric, 2019), sharing them on social networks, blogs, academic bookmarking services, reference managers, media, multimedia, channels, podcasts, preprints, and post-publication peer review sites (Piwowar et al., 2018). This exponential rise in data has led to issues related to the ethical handling of information, particularly fake news (Fernández-García, 2017), highly promoted in election campaigns or mass consumption products.

The speed of access to information justifies the need to transform educational systems to educate critical citizens, reflective thinkers, committed to their reality and capable of making decisions based on evidence and knowledge (Manassero and Vázquez, 2020; Vázquez and Manassero, 2019; González-Galli, 2016; Scheid, 2016; Amórtegui, Gavidia, and Mayoral, 2017; Rivas, Amórtegui, and Mosquera, 2017). The lack of critical reading of reality has contributed to the rise of a trend on social media that fosters distrust, rumors, and paranoia. These approaches make it necessary to analyze the conceptions that individuals, mainly in-service teachers, build about technology (Ortega and Perafán, 2016), biodiversity (Pérez, 2019), and culture (Melo, 2017).

Del Vicario et al. (2016) analyze the rise of two narratives in the technological niche: one stems from conspiracy theories, and the other is scientific information. They conclude that the social ecosystem that social media has become presents a similar consumption pattern in both narratives but differs in the cascade effect of fake news, as they become echo chambers that polarize and undermine the truthfulness of information.

In this context, critical thinking is vital in the processes of civic education, particularly in Colombia, a megadiverse and multicultural country with a series of social inequities and inequalities. Therefore, the efforts of educational institutions that promote the construction of knowledge and the development of skills, abilities, attitudes, and values to solve problems and make informed decisions need to be highlighted. From this perspective, critical thinking is a reflective, conscious, and dynamic process that leads to action. It is a metacognitive skill that helps individuals reflect on what they think and can do.

Scientific education, from a critical perspective, is transformative, based on understanding what science is and how it works. It also articulates an epistemological and sociological perspective regarding scientific knowledge's validation and social configuration. Likewise, another purpose of the integration between Science, Technology, and Society is the positioning of the Nature of Science and Technology in the processes of scientific education. Another merit of the didactic treatment of socioscientific issues, socially relevant aspects, or socially alive questions (Porras and Torres, 2019) is the strengthening of values such as respect, recognition of others, empathy, solidarity, tolerance, collaboration, among others, which serve as mechanisms of resistance against those devices generated from uncritical positions inherent in conspiracy narratives.

To promote the development of critical thinking skills in the context of science education, this study aims to improve the understanding of the Nature of Science and Technology among high school students in a public school in Bogotá. Specifically, it focuses on developing critical thinking in Physics through implementing a Teaching and Learning Sequence titled "Footprints."

Theoretical Framework

Critical Thinking

Critical thinking (CT) is one of the fundamental skills in the 21st century (Blair, 2019). To discuss and understand the quality of thinking and the role of the school in generating conditions for inquiry, research, and problem-solving through arguments—evaluated and communicated from complex and diverse intellectual perspectives—attitudes, knowledge, competencies, skills, and practices must be demanded. Expanding the significance of critical thinking requires reviewing the various perspectives under which the concept has been assumed and how it should be taught and evaluated.

Real approaches to addressing CT arise from Facione's contribution in the 1990s (Fisher, 2019) based on a consensus statement by experts, defining conditions to impact educational practices by transforming routine teaching and assessment. The Delphi method concludes that critical thinking requires cognitive skills and adequate dispositions emphasizing content knowledge and self-regulation to make value judgments in any situation. Tung and Chang (2009, p. 291) consider that a critical thinker, particularly a critical reader of reality, has the ability to differentiate facts from opinions, understands literal or implied meanings, as well as the tone of the narrator or those passing judgment, discovers causal relationships or connections between events, detects an inferential relationship from observed details, has sensitivity to perceive different points of view, makes fair judgments, and applies what they have learned in other contexts and domains (Wilson, 2012; Wright, 2015).

The concept of a critical thinker varies among different authors. Norris and Ennis (1989) consider that CT focuses on reasoned and reflective thoughts that allow individuals to decide what they believe or do. This characteristic arises from individual and collective praxis, enabling the construction of contexts of meaning about various problems that can be addressed in classroom work. Thus, Halpern (2003) defines critical thinking as the "use of cognitive abilities or strategies that increase the probability of a desirable outcome. It is purposeful, reasoned thinking directed at goals. It is the thinking involved in problem-solving, making inferences, calculating probabilities, and decision-making" (p. 6).

Argumentation

According to Vega-Reñón and Olmos (2012), the theory of argumentation has had three orientations in its history: the first comes from logical analysis, aiming to recognize how propositions are justified by others; the second comes from dialectics, highlighting discursive activity seeking rational persuasion and convincing others; the third comes from rhetoric, aiming to assess the discourse's conduct, sources and persuasion resources, as well as the speaker's style. Different approaches or perspectives for developing argumentative skills in science classes focus on creating practical conditions to achieve linguistic cohesion, acknowledging discursive and rhetorical orientations as forms of interaction among individuals through speech acts.

The identification, analysis, and evaluation of good arguments require considering their foundations or strengths and the discursive interaction evident in debates or controversies to resolve differences of opinion and influence people's behavior and opinions. It attempts to identify and describe persuasive resources constructed from agreed-upon rules. These three orientations require theoretical, methodological, epistemological, pedagogical, didactic, and psychological dispositions to analyze and evaluate argumentative discourse in science class. According to Schwarz and Baker (2017), argumentation is central to science education, allowing students to achieve higher cognitive, social, and moral levels and appropriate scientific discourse in line with science's epistemic work.

Addressing argumentative skills and their implications for science education requires exploring different avenues—scientific writing, controversies, social disputes, scientific practices, and participation in digital environments, among others—to motivate students to read scientific theories and concepts critically. Additionally, it promotes an understanding of the scientific enterprise's functioning and everyday decision-making processes (Bricker and Bell, 2008).

Methodology

This study follows the principles of mixed methodology, which involves collecting, selecting, analyzing, and interpreting qualitative and quantitative data to study a particular phenomenon (Leech and Onwuegbuzie, 2009). The quasi-experimental methodological design guiding the research aims to "test the existence of a causal relationship between two or more variables. When random assignment is impossible, quasi-experiments—similar to experiments—allow estimating the impacts of treatment or program, depending on whether they establish an appropriate comparison base" (p. 58). From this perspective, the use of pretests, the implementation of a didactic strategy called the Teaching and Learning Sequence (TLS), and the use of posttests constitute axes from which Critical Thinking (CT) skills and a better understanding of the Nature of Science and Technology (NoST) are promoted.

The study population comprises 13 eleventh-grade students from the Santa Librada district school in Bogotá, aged between 15 and 17 years. Among the study objectives is integrating CT and NoST skills, aiming to promote a space for reflection on teaching and learning strategies based on problem-solving. In this sense, a study of research on critical thinking in science education in the Colombian educational system is carried out using the Scielo and Dialnet databases. Additionally, there is a reflection on didactic strategies that can allow the deployment of CT skills in the study population. Therefore, within the working group, a pretest, strategy, and posttest research design was employed based on the methodological proposal of the CYTPENCRI project, using validated instruments employed in different investigations (Cobo, Abril, and Romero, 2019; Halpern, 2010; Vázquez, Acevedo, and Manassero et al., 2006).

Initial phase

The Halpern Test (Halpern Critical Thinking Assessment Using Everyday Situations, HCTAES) is employed to assess specific critical thinking skills, consisting of 25 items associated with everyday situations that must be answered openly or closed. These items are distributed across five dimensions inherent to critical thinking: verbal reasoning, argument analysis, hypothesis testing, probability and uncertainty, decision-making, and problem-solving. Regarding argumentative skills, five items are selected to determine if the student constructs an argument around everyday situations, as indicated in Table 1:

Table 1. *Objectives of the five situations from the Halpern Test addressed by students*

Situation 11	Category: Argumentation
Objective: Determine if the student recognizes the possibility that the country can have a strong economy, even if the government is not doing a good job.	
Situation 12	**Category: Argumentation**
Objective: Determine if the student identifies the key components of an argument: the conclusion, reasons, and counterargument.	
Situation 13	**Category: Argumentation**
Objective: Determine if the student can generate an argument that includes a reason, a conclusion, and a counterargument.	
Situation 14	**Category: Argumentation**
Objective: Determine if the student can recognize a fallacy.	
Situation 15	**Category: Argumentation**
Objective: Determine if the student can formulate an opinion, a reason, and a conclusion.	

Source: own elaboration.

To assess students' attitudes involving opinions on situations related to the Nature of Science and Technology, 9 questions from the Science and Technology Opinions Questionnaire (COCTS) on the external sociology of science were filled out.

Development Phase

The didactic intervention instrument is the Sequence of Activities called "Observation in Science," developed within the framework of the EANCYT project. Its purpose is to improve the understanding of observation and establish differences between looking, observing, and inferring. The activities developed correspond to the "Mysterious Clues" section, where students are presented with figures showing a sequence of traces, asking them to respond to what they observe to conclude that an inference is an interpretation of what is seen.

Table 2. *Learning Sequence* (*LS*)

Time	Activities (students/teachers)	Methodology/organization		Materials/resources
	HOOK Introduction-motivation			
15 min	They give examples / Scientists are always proposing ideas or theories to explain the things that happen in the world.	Whole class		Verbal
	ELICIT Previous knowledge			
15 min	They give examples / Sometimes new ideas arise because old ideas don't fit to the observations.	Whole class		Verbal
	Developing activities			
	EXPLAIN Contents			
15 min	They ask and listen / An observation is that you see.	Whole class		Examples
	EXPLAIN Procedures			
45 min	Create ideas / What do you know? observe in the figure?	Individual	Figure 1*	Predesigned figures
	They write their ideas observation on figure 1 /			
	Display figure 1	Inductive	Figure 2*	
		Display figure 1, then figure 2, and finally figure 3		
	They write their ideas observation about the figure 2 / Display figure 2	Whole class	Figure 3	
	They write their ideas observation about the figure 3 / Display figure 3		(Displayed figures. Annex 1)	
	They ask and listen / An inference is an interpretation of what is seen.			
30 min	EXPLAIN Attitudes			
	Each student orders and Reads their ideas to the group.	Students in groups of 3	Sheets written by each group	List of observations in sheets
	Open-mindedness to accept all new ideas.			
	The group makes their list of observations / Regulates discussions			
15 min	EXPLORE Consolidation			
	Argue and discuss ideas exposed by each group / Differentiate contributions which are observations of which are inferences.	Groups	Individual and group lists	

Time	Activities (students/teachers)	Methodology/ organization	Materials/resource
	Each group makes a new list of observations and inferences / Regulates	Individual	List per group
	They ask and listen / Conclusion: an inference It's an interpretation from what is seen; several inferences are possible.	Individual	
	EVALUATE		
	Instruments (select COCTS issues to evaluate).	Pre-postest	40211, 40221, 40231, 40311, 40321, 40411, 40421, 40441, 40451.
	EXTEND Reinforcement activities		
20 min	They prepare writing a final personal story / Regulate, supervise.	Individual	
	EXTEND Expansion activities		
25 min	Conclusions are applied about looking, observing, and inferring with own situations of physics: kinetics and dynamics of bodies.	Individual	

Source: own elaboration.

Final Phase

The evaluation of the effectiveness of the didactic intervention was carried out based on the comparison between argumentative skills before and after implementation. Similarly, students' attitudes toward these topics—evidenced in the responses to the 9 COCTS questions related to the external sociology of science—demonstrate a tendency to change before and after didactic treatment.

Results and Analysis

To verify the effectiveness of the didactic sequence in the development of argumentative skills and a better understanding of the Nature of Science and Technology, the pretests and posttests of the five situations from the Halpern Test on argument analysis and the ten COCTS questions related to the external sociology of science were considered—understood as the type of relationships that students establish between society and the Science and Technology system.

This assessment of the relationships between CT and NdCyT gives particular importance to scientific and technological education, which promotes citizenship committed to decision-making, especially on real-life issues related to CyT (Acevedo, 2004). In this regard, Vázquez, Acevedo, and Manassero (2005) propose

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a humanistic, scientific education based on scientific and technological literacy for citizenship by transforming the closed classroom into a system open to reality. This perspective allows the research results to be transferred to other contexts of significance, which, for the present study, converge on the arguments that students construct in the face of everyday situations related to science and technology.

Results Halpern Test Questionnaire and Adaptation of the Didactic Sequence

The HCTAES questionnaire was applied—modified before and after the learning sequence titled "Mysterious Clues"—to verify the effect of the didactic intervention on the argumentative skill development of the 13 students who participated in the study. The HCTA has a high level of reliability due to its unique scoring method. Participants respond to prompts demonstrating their ability to reason verbally, analyze arguments, verify hypotheses, recognize probability and uncertainty in everyday situations, make informed decisions, and solve problems.

The construct validity of the HCTA has been evaluated in a series of studies, including pre-posttest experimental designs, in samples that include high school and university students and pre-service and in-service teachers from numerous countries. The 25 situations include everyday scenarios demonstrating a general critical thinking factor and separating the recognition and recall facets (Butler, 2012).

1. Situation 11-P2, the first of the argumentation dimension, aims to determine if the student recognizes the possibility that the country can have a good economy even if the government is not doing a good job. According to the presented results, there were no significant changes in the students' responses before and after the didactic intervention, indicating difficulty in choosing an option to develop a solid argument against the reference statement.

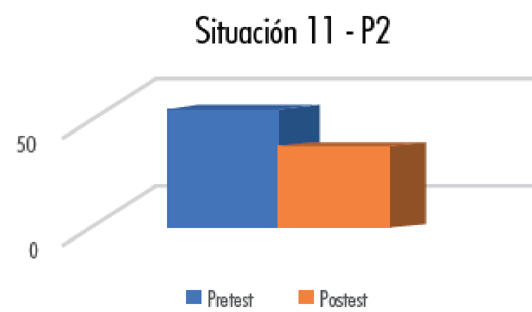

Figure 1. *Pretest and Posttest Results for Situation 11-P2*

Source: Own elaboration.

According to Bañales et al. (2014), one of the obstacles for university students, coinciding with the last year of high school, is understanding that the types of tasks and inquiry-related questions linked to disciplinary argumentation require an understanding of the types of controversial questions formulated within the disciplinary domain. Therefore, students should be introduced to the context of academic reflection as a challenge for scientific and technological literacy. From this perspective, the didactic sequence allowed students to observe, at a basic level, the images presented concerning the "mysterious footprints," which led to some uncritical generalizations regarding each of the three figures presented. In the first case, all students indicate that the presented footprints belong to two animals, bipeds perhaps birds. One student (E8) suggests that one of the birds has a constant movement based on its footprint type: "One has a constant path and leaves the other in a few steps."

The results of the first activity of the learning sequence suggest that students face difficulties in making conjectures about the alternatives presented to them, leading to conclusions related to basic observations from the preliminary description of the situation. Therefore, it is necessary to introduce the analysis of everyday situations related to mechanics, aiming to construct arguments and individual and collective elaborations. Approaching these qualitative reasonings involves following the discursive interactions through which students develop and express their ideas. Consequently, it is crucial to explicitly guide them on the conditions that allow them to develop feasible arguments.

Based on the preliminary results, some methodological elements (Kingsbury, 2019) adapted to the learning sequence are included, contributing to students' constructing plausible arguments. A situation is presented in the context of passenger transport by bus, in which students infer the direction in which people fall when braking suddenly. Students are asked to explain where they fell and answer the following questions:

a. Write the reasons to deduce that this is a good explanation. If you do not believe the explanation, think: What reasons could someone have to believe in that conclusion?

   The reasons provided by the students revolve around adapting some concepts from physics that would make the argument more robust (Vizcaino-Arévalo and Terrazzan, 2015). In fact, 11 students (85%) include the principles of inertia in the explanation, stating that:

   "Inertia is the property that all bodies have to remain in a state of rest or motion until an external force changes their state" (E13).

   "The bus braked, and inertia acted" (E9).

   "When the bus brakes suddenly, the force of inertia causes the person to move at the same speed as the bus" (E4).

b. Focus on one reason or group of related reasons. Consider whether there are any undeclared premises that should be added before those reasons support your conclusion. If there are, add the premises.

   Half of the students include new explanatory elements focused on the reasons that allow elucidating the situation:

   "When the bus brakes, the person has a driving force that the bus had and continues with that driving force" (E10).

   "The bus has a speed that, when braking, acts on the individual" (E4).

   "People have the same speed as the bus" (E7).

c. Consider if your initial premises and your undeclared assumption are plausible. Do they need additional support for the public to accept them?

   In this part, students are asked to introduce the elements from points 1 and 2 to build a conclusion:

   "When the car brakes, inertia displaces people forward because they have the same speed as the bus" (E2).

"As the bus is in motion, passengers will follow the speed the bus had unless something stops them" (E5).

d. Evaluate your argument as if it were someone else's. Consider what objections a capable and knowledgeable person might raise. Are the premises plausible as they are, or do they need more support? Do the premises provide enough support for the conclusion? If true, would they make the conclusion probable enough? If not, adjust your argument accordingly. One way to test the amount of support that premises provide to the conclusion is to try to construct counterexamples: see if you can think of any situation in which the premises are accurate, but the conclusion is false.

When evaluating the components of the argument, students are asked to consider another similar situation to the one analyzed. The group reaches the conclusion of explaining what happens when two bumper cars collide. Assertions, reasons, guarantees, evidence, counterarguments, and support are verified, translating into plausible explanations that involve elastic collisions and Newton's third law:

"It's Newton's third law, it says that if we apply a force to an object, it reacts with a force of equal magnitude" (E8).

"The cars will bounce off each other when they collide, and if you're in the car, inertia will bring you back" (E5).

"When the cars collide, they move in opposite directions due to the force they had" (E3).

2. Plausible results regarding situation 12-P2 of the modified HCTAES questionnaire allowed determining if students identify the key parts of an argument: the conclusion, reasons, and counterargument in a situation that involves choosing a professional career (Figure 2). There is a significant improvement in students' responses, specifically in items 2 and 4, which refer to crafting a conclusion and a reason. Items 1 and 3, related to the reasons for an argument, received the same responses in the pretest and posttest. However, it is highlighted that nine out of the 13 students considered the exciting aspect of a career as the fundamental reason for choosing it.

Likewise, there is a difficulty in recognizing counterarguments. Students seem to stick to their basic form, acknowledging a statement and a reason but not fully grasping the complex structure of an argument regarding statements, reasons, warrants, evidence, counterarguments, and backing (Bañales et al., 2015).

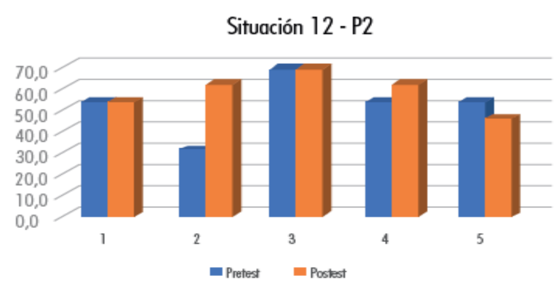

Figure 2. *Pretest and posttest results for situation 12-P2*

Source: Own elaboration.

3. Similar to the previous question, situation 13 P-2 aims to determine if the student identifies the conclusions, reasons, and counterarguments of an everyday situation related to the public service requirement to obtain a degree (Figure 3). There is a notable increase in appropriate responses in 4 out of 5 posttest items related to the components of an argument, such as reason —items 1 and 5—, counterargument —item 2—, and conclusion —item 3—. In the reason component, the posttest shows an increase of 23% in item

1 and 31% in item 2. These results can be explained by the students' progress in recognizing the reasons that support an argument.

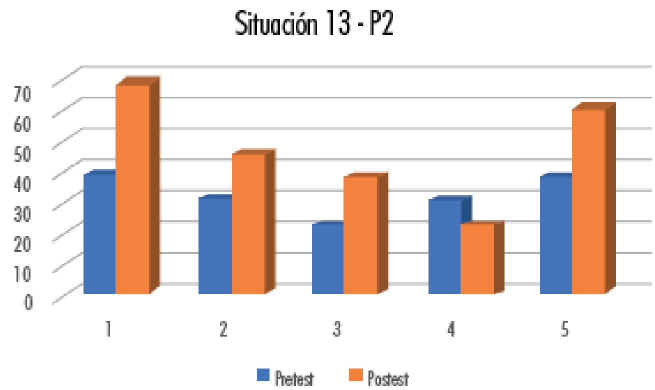

Figure 3. *Pretest and posttest results for situation 13-P2*

Source: Own elaboration.

The situation 14 P-2 determines if the student can recognize a fallacy. The presented situation focuses on analyzing a country's acceptance of more immigrants and the possibility of increasing quotas for all countries (Figure 4). The results for this question are very low both in the pretest and posttest. It is difficult for students to recognize an analogy of the presented fallacy, as the increase in the quota for several countries does not necessarily mean an increase for others. This situation emphasizes the importance of argumentation from the NdCyT, specifically in forming well-informed citizens who evaluate conspiracy theories or fake news. Thus, it is possible to recognize reasons, sources, evidence, and counterarguments.

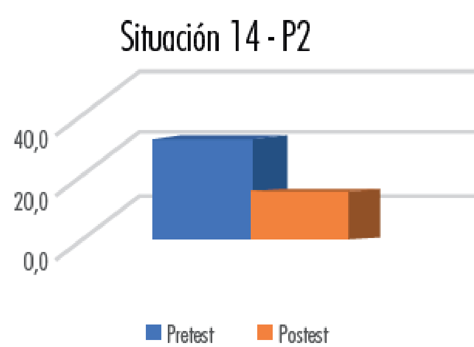

Figure 4. *Pretest and posttest results for situation 14-P2*

Source: Own elaboration.

From this perspective, it is necessary to engage students in activities that enable them to generate relevant knowledge through credible sources to have them take an informed stance in which they construct arguments and counterarguments based on evidence. Additionally, students should be encouraged to pose and solve questions that clarify, challenge, or confirm perspectives and facts.

The purpose of Situation 15 P-2 is to determine the student's ability to provide an opinion, a fact, or an argument in response to a situation: the mayor's decision to paint the buildings in a city with paint that allows for easy graffiti cleaning.

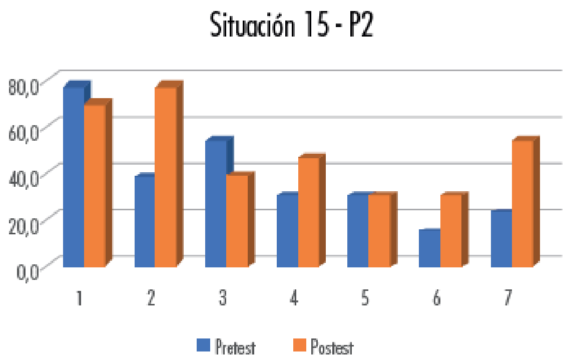

Figure 5. *Results of pretest and posttest for Situation 15-P2*

Source: Own elaboration.

Improved results in the posttest are inferred from student responses, particularly in items 2, 4, 6, and 7, which focus on recognizing facts and arguments. Items 1 and 5, corresponding to recognizing opinions, have relatively low scores, possibly due to students' difficulty distinguishing their debatable nature or a tendency to assume uncritical generalizations as valid positions. On the other hand, items 2 and 6, related to recognizing facts, show a significant increase in post-test results, demonstrating some students' ability to determine the characteristics of certain events. Items 3, 4, and 7 constitute arguments, with a low result for the first and a significant increase in the latter two, indicating an improved disposition to recognize reasons and conclusions, particularly justifications for or against the use of paint that facilitates graffiti cleaning.

Results related to the COCTS regarding the external sociology of science

The analysis of student responses to the nine questions of the COCTS related to the external sociology of science and technology allowed for the recognition of representations and opinions about the complex relationships between Science, Technology, and Society. According to some authors (Vázquez and Manassero, 2019; Massi and Linhares, 2019), these representations are reinforced in educational institutions with decontextualized views that must be debated, reflected upon, and mobilized from the students' formation.

In fact, some results confirming these ideas show that the average weighted scores for the nine questions applied in the pretest stage is slightly positive (+0.095). This demonstrates that the initial attitudinal trend of the students regarding the external sociology of science is moderate (Table 3). According to Vázquez, Manassero, and Acevedo (2005), evaluations of the statements are transformed into a global attitudinal index (range: -1, +1) through an interpretative method that requires a prior classification of the statements: appropriate, plausible, and naive.

Table 3. *Overall Results of Student Responses in the Pretest and Posttest Phase*

Issues external sociology	INITIAL				FINAL			
	Appropriate	Plausible	Naive	Weighted index	Appropriate	Plausible	Naive	Weighted index
40211	0,515	0,092	-0,523	0,023	0,183	0,039	-0,231	-0,003
40221	0,542	0,238	-0,192	0,192	0,327	0,413	-0,058	0,227
40231	0,731	-0,031	-0,015	0,223	0,481	0,183	0,154	0,272
40311	0,100	0,085	-0,400	-0,062	0,212	0,252	-0,423	0,013
40321	0,600	-0,108	-0,225	0,062	0,577	0,263	-0,481	0,120
40411	0,362	0,017	-0,008	0,131	0,250	0,346	-0,096	0,167
40421	0,369	0,077	-0,208	0,085	0,221	0,371	-0,212	0,127
40441	0,233	-0,025	-0,238	-0,023	0,231	0,404	-0,102	0,177
40451	0,717	0,008	0,033	0,225	0,462	0,353	0,019	0,278
Average	0,463	0,039	-0,197	0,095	0,327	0,292	-0,159	0,153

Source: own elaboration.

In the pretest, the highest weighted index with the most positive value (+0.225) is obtained in question 40451 regarding the exclusive role of Science and Technology in solving pollution problems. The most negative weighted index (-0.062) corresponds to the question related to the negative and positive effects of Science and Technology. As can be observed, the recognition of students' attitudes in terms of personal psychological dispositions, involving an assessment of the benefits and drawbacks of Science and Technology, is still in its early stages in the pretest phase. For these reasons, making decisions regarding the need for scientific and technological literacy that promotes contextualized critical thinking is advisable.

In the posttest, the highest weighted index with the most positive value (+0.278) continues to be question 40451, related to the responsibility of Science and Technology in solving pollution problems. The only negative weighted index in the posttest (-0.003) corresponds to question 40211 about the role of scientists and engineers in a country's scientific and technological decisions. The outlined considerations up to this point invite us to consider the evolution of students' responses concerning the ideas and attitudes they construct about the role of Science and Technology in society, highlighting the role of the contextualized didactic treatment presented in the SEA. In this way, the evolution in shaping the training processes from the perspective of the NdCyT is evident by comparing students' responses in the posttest and pretest (Table 4).

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Table 4. *Change in Student Responses (final-initial)*

Questions	FINAL-INITIAL CHANGE			
	Appropriate	Plausible	Naive	Index Average
40211	-0,332	-0,053	0,292	-0,026
40221	-0,215	0,175	0,134	0,035
40231	-0,25	0,214	0,169	0,049
40311	0,112	0,167	-0,023	0,075
40321	-0,023	0,371	-0,256	0,058
40411	-0,112	0,329	-0,088	0,036
40421	-0,148	0,294	-0,004	0,042
40441	-0,002	0,429	0,136	0,2
40451	-0,255	0,345	-0,014	0,053
Average	-0,136	0,253	0,038	0,058

Source: own elaboration.

As indicated in the table, eight of the nine weighted indices for the COCTS questions analyzed in terms of the external sociology of science and technology show a positive evaluation after the didactic intervention. While the values reflect a significant change in attitudinal indices in the posttest, they still remain moderate concerning expectations regarding the role of Science and Technology in society.

Final Considerations

The articulation of scientific and technological education processes with the development of critical thinking skills through a didactic proposal focused on argument construction has allowed students to consider important civic engagement that questions certain explanations related to the influence of Science and Technology on society.

The overall results in terms of argumentative ability and attitudes towards Science and Technology related to external sociology allow inferring that the work initiated with high school students aims, in principle, to educate citizens who learn to evaluate the credibility of information sources, identify explicit and implicit aspects of an argument—whether it be a statement, news, or conversation—plus reject conclusions that are not supported by valid reasons or escape critical scrutiny.

Recognizing Science and Technology as non-neutral processes that can sometimes fuel discrimination, inequality, and injustice justifies the need for a complex approach in the processes of civic scientific education. Consequently, the assessment of attitudes related to Science, Technology, and Society aims for students to develop and exercise the ability to capture inferential connections that support statements and learn metacognitive strategies of self-regulation, cognitive monitoring, and evaluation for better decision-making inside and outside the classroom.

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