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EMPIRICAL RESEARCH

Explicit and reflective teaching for the development of Critical Thinking skills and Nature of Science and Technology understandings in Primary Education

Ensino explícito e reflexivo para o desenvolvimento de competências de pensamento crítico e de compreensão da natureza da ciência e da tecnologia no ensino básico

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Abstract. This study seeks to contribute to the development of critical thinking (CT) skills and nature of science (NOS) concepts in primary education – more specifically, argument analysis (CT) and certain aspects of the external sociology of science, such as scientific decision making and the compromise between the positive and negative effects of science and technology (NOS). The study involved the participation of 72 students from 5 different schools. It was a mixed-design study, using tools such as questionnaires, observation charts and interview scripts. The results showed significant improvement in argument analysis questionnaire scores and in NOS concepts after the explicit and reflective work done in a teaching-learning sequence. These results were confirmed by classroom observation, the analysis of workbooks and student interviews within a month of the intervention. This enabled us to conclude that the intervention had a positive impact on the development of the skills and concepts under study, even in the face of variation as a result of differences in teaching-learning sequence implementation by different teachers in different contexts. The reflective teaching approach can be identified as one of the keys to intervention success.

Keywords: Nature of science, Critical thinking, Elementary education, Reflective teaching

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Resumo. O presente estudo pretende contribuir para o desenvolvimento de competências de pensamento crítico (PC) e de conceitos de natureza da ciência (NOS) no ensino básico - mais concretamente, a análise de argumentos (PC) e alguns aspectos da sociologia externa da ciência, como a tomada de decisões científicas e o compromisso entre os efeitos positivos e negativos da ciência e da tecnologia (NOS). O estudo envolveu a participação de 72 alunos de 5 escolas diferentes. Tratou-se de um estudo de desenho misto, com recurso a instrumentos como questionários, fichas de observação e guiões de entrevista. Os resultados mostraram uma melhoria significativa nas pontuações do questionário de análise de argumentos e nos conceitos da NOS após o trabalho explícito e reflexivo realizado numa sequência de ensino-aprendizagem. Estes resultados foram confirmados pela observação da sala de aula, pela análise dos cadernos de trabalho e pelas entrevistas aos alunos um mês após a intervenção. Tal permitiu-nos concluir que a intervenção teve um impacto positivo no desenvolvimento das competências e conceitos em estudo, mesmo perante a variação resultante das diferenças na implementação da sequência de ensino-aprendizagem por diferentes professores em diferentes contextos. A abordagem do ensino reflexivo pode ser identificada como uma das chaves do sucesso da intervenção.

Palavras-chave: Natureza da ciência, Pensamento crítico, Ensino básico, Ensino reflexivo

Introduction

Contemporary society and the lifestyles associated with it draw on scientific and technological developments. This makes scientific literacy a must at the global level, enabling both the understanding of science and technology, and a critical view of the influence they have on

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society, as well as of the associated socio-environmental needs and the consequences of the environmental crisis. The Agenda 2030 for Sustainable Development emphasises the role of education in sustainable development. As observed by Tenreiro-Vieira and Vieira (2021), quality education, as envisaged in Goal for Sustainable Development 4, is essential for the development of critical thinking (CT), creative thinking, communication, collaboration, and cooperative, responsible citizenship.

In the past few years, scientific and technological literacy has become a goal of science education, and nature of science (NOS) knowledge is one of its key components (Acevedo et al., 2017; Pleasants et al., 2019). As pointed out by Taber (2017), science education must include both science content, and knowledge of science and how it leads to the production of further knowledge (NOS). Some authors point out that NOS knowledge is easier to acquire when students have CT skills (Vázquez and Manassero, 2018; Yacoubian and Khishfe, 2018), since scientific thinking draws on a variety of CT competencies (Rezaei and Saghazadeh, 2022). In the same vein, they see the need for PC development to address NOS issues such as practice making judgments on what views of NOS to acquire, or practice making decisions on socioscientific issues through applying their NOS understandings.

The development of CT competencies and literature should include: (1) the acquisition of scientific knowledge; (2) the development of a set of strategies, skills and habits to implement effective thinking processes (making good decisions, building evidence-based arguments, analysing information, and so on); (Ritchhart et al., 2014; Swartz, 2013); (3) the willingness to use the acquired skills and apply the acquired knowledge; (4) the subjection of all of the above to context-specific rules and ethical standards (Tenreiro-Vieira and Vieira, 2020).

Objectives

This study is aimed at improving CT skills and NOS concepts in 11- and 12-year-old students. Accordingly, the research objectives are:

- To test whether nature of science (NOS) concepts associated with the societal impact of science and technology improve after implementing a teaching-learning sequence (TLS), particularly in the following areas:
    - decision making in science matters.
    - compromise between the positive and negative effects of science and technology.
- To test if CT skills in argument analysis improve after implementing a TLS.

Theorical background

The Nature of Science

NOS is defined as 'metaknowledge of science, based on the interdisciplinary views of philosophers, historians and sociologists of science' (Acevedo et al., 2016, p. 914). As a construct that is part of the school curriculum, it can be approached from different perspectives, including the 'Lederman seven' (Lederman et al., 2002), expanded by Matthews (2012); the consensuses defined by McComas (2002) on the basis of science education policy documents; the consensuses drawn from the study by Osborne et al. (2003) which presents agreements from a perspective focused on curriculum construction; Irzik and Nola's family resemblance approach (FRA) (2011, 2014), reviewed and expanded in Erduran and Dagher (2014) and Dagher and Erduran (2016); and the science, technology and society (STS) tradition applied to science education (Manassero and Vázquez, 2019).

To understand the commonalities between the different ways of conceiving NOS mentioned above, a content analysis is carried out in order to establish a theoretical baseline. We have carried out this analysis by selecting four categories (technology and definition of science and technology; epistemology; internal sociology of science; and external sociology of science) and classifying the items of the taxonomies put forward by the different authors according to these categories. This classification was reviewed by three experts in the field, who did not propose any changes to the classification (Figure 1).

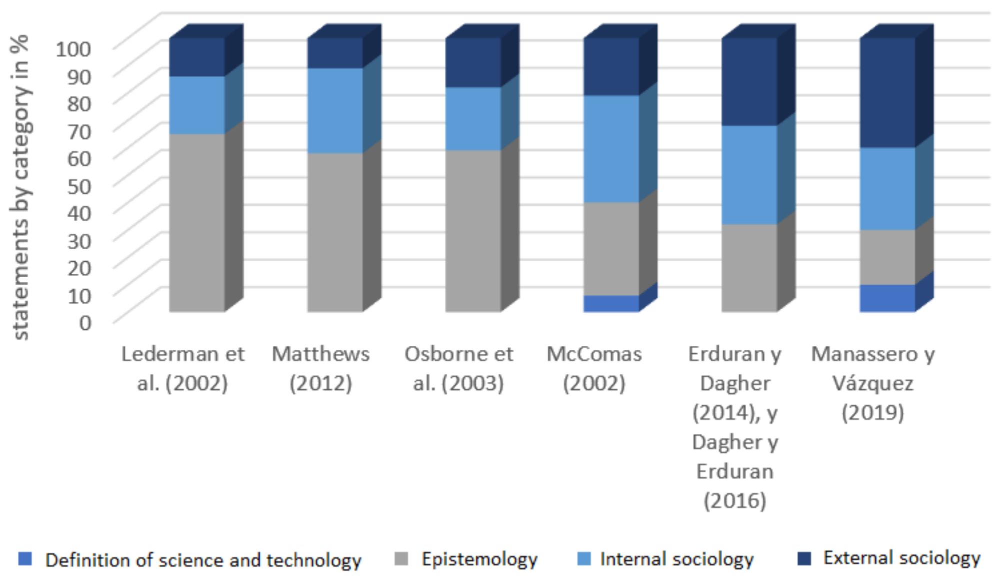

Figure 1. Authors' consensus according to NOS categories. Source: Own elaboration

In this way, it can be seen how: (1) the consensuses set out by Lederman et al. (2002) are predominantly epistemic; (2) Mathew's (2012) addition to these includes some elements more typical of the internal sociology of science, a trend continued by Osborne et al. (2003); (3) McComas' proposal shows an increase in the participation of the category of internal sociology; (4) it is in the proposed agreements Manassero et al. (2001) updated in Manassero and Vázquez (2019) and Irzik and Nola (2014) completed by Dagher and Erduran (2016), where a significant increase in the category of external sociology of science.

If we continue to look at the works of Dagher and Erduran (2016) and Manassero and Vázquez (2019), as those that most develop the category of external sociology of science, we can observe several points in common. We focus on this element as it is central to this study. The external sociology of science analyses how external social, political, economic and cultural factors influence science (Vázquez et al., 2013; Yalvac et al., 2007). In other words, this perspective examines the environment in which science develops since science does not develop in isolation but responds to social interests and power groups. In this way, the work of external sociology in the classroom avoids the identification of the development of science with rationality, giving way to an understanding of the various influencing variables. Among these authors, we have chosen to take Manassero and Vázquez as a reference because his taxonomy has more presence the technology and its interactions with science and society in the formation of the construct. In Dagher and Erduran (2016) the authors speak of an approach taking into account the STS perspective, however, and in our opinion, this perspective is more concrete in Manassero and Vázquez (2019) who refer to aspects related to the influence of science and technology on society (specific elements of study in this research). Consequently, Manassero and Vázquez's taxonomy is determined as the theoretical basis for the study and we establish and more specifically place ourselves in the category of external sociology, which in turn includes elements such as: Society's Influence on Science and Technology; Triadic influence - STS interaction; Influence of School Science on Society; and Societal impact of science and technology. Specifically, the study focuses on the influence of society on science and technology through two particular aspects: the positive and negative effects of science and technology and the role of society, scientists and engineers in energy-related scientific decision-making.

NOS education can adopt two different teaching approaches: implicit or explicit. Both have been applied for decades now in science curriculum reforms in various countries. Studies show that explicit approaches, especially reflective ones, are more effective when it comes to teaching NOS (Acevedo, 2009; Manassero-Mas and Vázquez, 2023). Consequently, the didactic approach of the study will be made explicit. Also, despite the fact that this study takes a holistic NOS construct as its point of reference, it is understood that in classroom situations with very young learners it is very complicated to show this perspective. Consequently, specific elements of the external sociology of science (dimensions of NoS) are proposed for application in the classroom, as in other studies (Acevedo et al., 2017; Cobo-Huesa et al., 2022). In this way, primary school students begin to acquire notions that facilitate the construction and understanding of the global construct at higher educational levels.

Critical thinking (CT) skills and scientific thinking

According to Ortega-Quevedo et al.:

> [CT is] a set of processes deliberately implemented to draw conclusions on a variety of topics and to analyse how these conclusions were reached. By applying CT processes, related data or problems that need to be solved are broken down, synthetised and thoughtfully assessed to reach a conclusion or a solution. The conclusion or solution is also analysed to see if it can be improved. (Ortega-Quevedo et al., 2020, 94)

Although a variety of CT taxonomies exist (Ennis, 1996; Facione, 1990; Halpern 2014 among others), there is consensus that CT comprises a set of cognitive competencies, a dispositional component, a set of rules that apply to the context of thinking, and the knowledge in which the thinking is grounded (Tenreiro-Vieira and Vieira, 2021).

According to Halpern (1998), the cognitive component of CT can be divided into five skills: argument analysis, verbal reasoning, hypothesis testing, problem solving, and likelihood and uncertainty. In this taxonomy we can clearly see the similarities between the components of scientific thinking and those of CT itself (Vázquez and Manassero, 2018). The detection of these connections has led us to find studies in the field of science education that investigate the development of capacities that coincide between critical thinking and scientific thinking (Erduran et al., 2006; Jiménez-Alexandre and Puig, 2012; Porras et al, 2020; Quijano et al., 2014; Tenreiro-Vieira and Vieira, 2021; Torres and Solbes, 2016, 2018; Vega and Callejas, 2020; Zeidler, 2003) as well as studies focused on analysing the potential of developing PC skills to improve understanding of NdCyT or studying how improved conceptions of NdCyT contribute to PC development (Torres and Solbes, 2016; Vázquez and Manassero, 2018; Manassero, Vázquez, 2019).

Bearing in mind the scientific evidence, the objective and the context in which this research is developed, specifically, this study will focus on the analysis of arguments, since argumentation is related to the social aspects of science and the development of argumentation skills is part of science education (Khishfe, 2022).

According to Halpern (2014), argument analysis includes the ability to understand arguments and their components: reasons, assumptions, qualifiers, counterarguments and conclusions. An argument is a set of statements with at least one conclusion and one reason that supports the conclusion; these are the main parts. The study analyses the identification and use of arguments (a statement that reflects an individual’s position), counterarguments (a statement that opposes a previous argument) and conclusions (final position or decision in an argument).

In this study, the teaching of this CT skill is addressed under the so-called PIGES principles, where P stands for *principiar* (begin to do), I for *intencionalmente* (intentionally or deliberately), G for *gradualmente* (gradually), E for *explicitamente* (explicitly) and S for *sistematicamente* (systematically) (Tenreiro-Vieira and Vieira, 2021). The process thus includes: (1) introducing students to the development of thinking and knowledge at an early age; (2) teaching in context and intentionally; (3) moving gradually, according to the students’ level and the context; (4) identifying and teaching the skills that need to be developed explicitly; (5) being systematic in teaching throughout the school years.

Methods

The study analyses classroom sessions with various teachers trained in the areas addressed in the TLS (NOS, CT and energy), using a longitudinal multi-method design (three months’ time). For the selection of these participants, the possibility of participating in the project was offered, highlighting the work of the three constructs involved (NOS, CT and energy). The interested schools and teachers, together with the classrooms they tutored, are the participants in this project. To train the teachers, a course was started to present the theoretical bases on which the proposal is based in relation to NOS, CT and energy, as well as the activities designed and how to dynamize them in the classroom. This training is essential to help teachers to avoid conceptual errors and to apply the materials in an optimal way (Voss et al., 2021) and promote equitable scientific teaching (Librea-Carden and Mulvey, 2023). This is to avoid problems such as those encountered when online materials are implemented without training and with questionable material quality (Summers, 2024). The researcher had a non-participant observer role in the classroom.

Given the complexity of the object of study, both quantitative and qualitative methods were used, to enable data triangulation and to offset the shortcomings of one method with the benefits of another in data analysis (Figure 2).

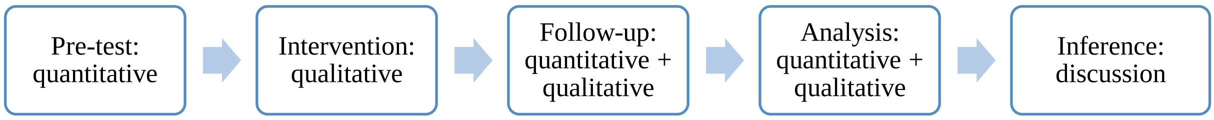

Figure 2. Phases of the multi-method design. Source: Own elaboration

Participants

The study involved the participation of 72 11- and 12-year-old students from five courses in three schools in Segovia, Spain (Table 1), selected by convenience sampling (Alaminos and Castejón, 2006). Permission to conduct the study was sought from the relevant education authorities who approved the research on ethical grounds. Subsequently, schools were contacted for an information session on the project. Finally, the families of participating students were asked to give informed consent.

Table 1. Participants in the study by schools and groups.

Groups	Participants			Cultural level	Economic level[1]	Openness to methodology[2]
	Boys	Girls	Total			
School_2_Group_5A	6	7	13	High	Upper-middle	Average
School_2_Group_6A	6	7	13	High	Upper-middle	Average
School_2_Control_Group	9	8	17	High	Upper-middle	Average
School_5_Group_6B	5	5	10	High	Upper-middle	Average
School_6_Group_6A	12	7	19	Middle	Middle	Low
	38	34	72			

1 and 2: Determined through the analysis of the school's projects and informal talks with the regular classroom teachers.

Out of the five participating groups, one was used as control group. The validity of the control group was determined using the Kruskal-Wallis H test, comparing the pre-test data to the data for the other groups as a whole and individually. The test showed p-values of more than .05 for all variables and thus proved the initial statistical equivalence between the control group and the experimental groups for all variables. The control group has a similar size to each group-class, which is considered of interest for the study, as contrasts are made between groups-classes.

As for the sample interviewed, regular classroom teachers were asked to choose three students each, with varying levels of learning achievement (high or advanced/average/low), for the interviews.

In order to ensure the confidentiality codes were assigned for gender (M for male; F for female), school number, group and level of learning achievement (A for advanced [alto]; M for average [medio]; B for low [bajo]).

Research tools and techniques

The main research technique was interrogation with instruments like adapted Views on Science-Technology-Society (VOSTS) questionnaire as validated by Ortega-Quevedo and Gil-Puente (2019) and the critical thinking assessment tool validated by Ortega-Quevedo et al. (2020). As a complement to these quantitative instruments to provide further information, evaluation rubrics and observation charts were applied to student productions. In addition, as shown in Figure 2, an interview was used to analyze the long-term development of the pupils.

Adapted VOSTS

This tool, designed for 11- and 12-year-old students, was used in the pre-test and post-test research phases. The analysis focused on the results for items 40211 and 40311, set of elements that make up the category of the external sociology of science (Figure 3).

Adapted ítem 40211
Scientists and engineer should be the only ones to decide the scientific issues in our country because they are the people who know these issues best. They are the people who know best about these issues, such as the types of energy (nuclear, hydro, solar, coal, etc.), or nuclear disarmament.
Statements to take into account
- Scientist and engineers are the ones who should decide because they have training and the data to better understand the issue.
- The decision should be mate on a shared basis. The opinions of scientist and engineers and informed citizens should be taken into account in decisions that affect our society.

Adapted ítem 40311
There has to be a compromise between the positive and negative effects of science and technology. Yhere always are compromises between positive and negative effects.
Statements to take into account
- The long-term effect of new scientific development cannot be predicted, no matter how thorough initial studies are.
- There can be no positive results without testing ideas, which means that the negative consequences have to be deal with.

Figure 3. Items from the adapted VOSTS questionnaire (Ortega-Quevedo et al., 2022a, 228)

Critical thinking assessment tool

This tool is used to assess students' argument analysis skills in the classroom in phases 1 and 3 of the research process (pre-test and post-test phases) (Figure 4).

Situation for argument analysis assessment:
There are many job opportunities for computer experts. You should specialize in this area. It is an interesting job, with bright career prospects and high salaries. If you are not too good at maths or you like to be outdoors, then it might not be the right job for you.
Students are asked to identify reasons, counterarguments and conclussion in the statements

Figure 4. Situation to apply the critical thinking assessment tool (Ortega-Quevedo et al., 2022a, 228)

Observation charts

The study resorted to checklists for systematic observation (Nieto, 2010). The checklists were completed during the sessions. Their items (Figure 5) reflected the elements under study (they were relevant for the development of argument analysis skills or for the understanding of decision-making processes in technological and scientific matters and the need for a compromise between the positive and negative effects of science and technology).

Items to be observed about critical thinking
- Use arguments
- Supports the arguments of peers or presents counter-arguments
- Contrasts hypotheses about questions through the arguments presented and is able to modify them
- Reformulates hypotheses based on the evidence presented in the debate

Items to observe on the acquisition of NOS concepts
- Recognises types of energy and identifies them in nature and in man-made situations
- Understands the importance of the properties of energy
- Understands the relationship of energy to science, technology and society

Figure 5. Items for systematic observation

Rubrics

A rubric is commonly defined as a scoring tool that articulates the expectations for an assignment by listing criteria and describing levels of quality for each criterion (López-Pastor and Pérez-Pueyo, 2017). For the assessment of student productions, the study used the rubric validated by experts in psychology and experimental science education, and by elementary school teachers as well (Figure 6). The rubric was applied to a review of the exercises in the students' workbooks, grading them according to the rubric's scale. For instance, in the case of a question like:

> 'Who should decide on the energy resources we use in Spain?', student answers such as 'The scientists who know about energy, and the people' would be scored as high-level according to the fourth criterion in the rubric; statements along the lines of 'Those who know about energy, with the approval of government authorities and the

people' would be classified as average, and answers like 'Government' would get low scores. (Ortega-Quevedo et al., 2022a, 229)

Items on NOS content
- Decision-making on scientific issues
- Trade-offs between positive and negative effects in science and technology
- Citizen control of technology

Items on critical thinking
- Expresses the full conclusion, supported by valid evidence
- Expresses several reasons supported by valid evidence
- expresses several counter-arguments supported by valid evidence
- Analyses the arguments and evidence presented and checks the validity of his/her hypotheses against the new evidence. Modifies these hypotheses if necessary

Figure 6. Items included in the rubric

Interview scripts

The study used individual semi-structured interviews that followed a script (Albert, 2009), validated by researchers specialising in experimental science education (Figure 7).

Questions to analyse critical thinking on NOS issues
- Do you know who should make decisions regarding scientific issues such as energy sources? And have you thought about this before?
- Why do you think there needs to be trade-offs between the negative and positive effects of science and technology, and have you thought about this before?
- Do you know if citizens are in control of technological development, and have you thought about this before?

Figure 7. Items of the interview

Overview of the relationship between the different data collection instruments

As indicated above, the different research instruments are closely related. The construction of the qualitative instruments derives from the quantitative instruments to carry out a process of triangulation that allows us to acquire a deep and broad vision of the studied reality. Figure 8 shows the relationship between the different items described above.

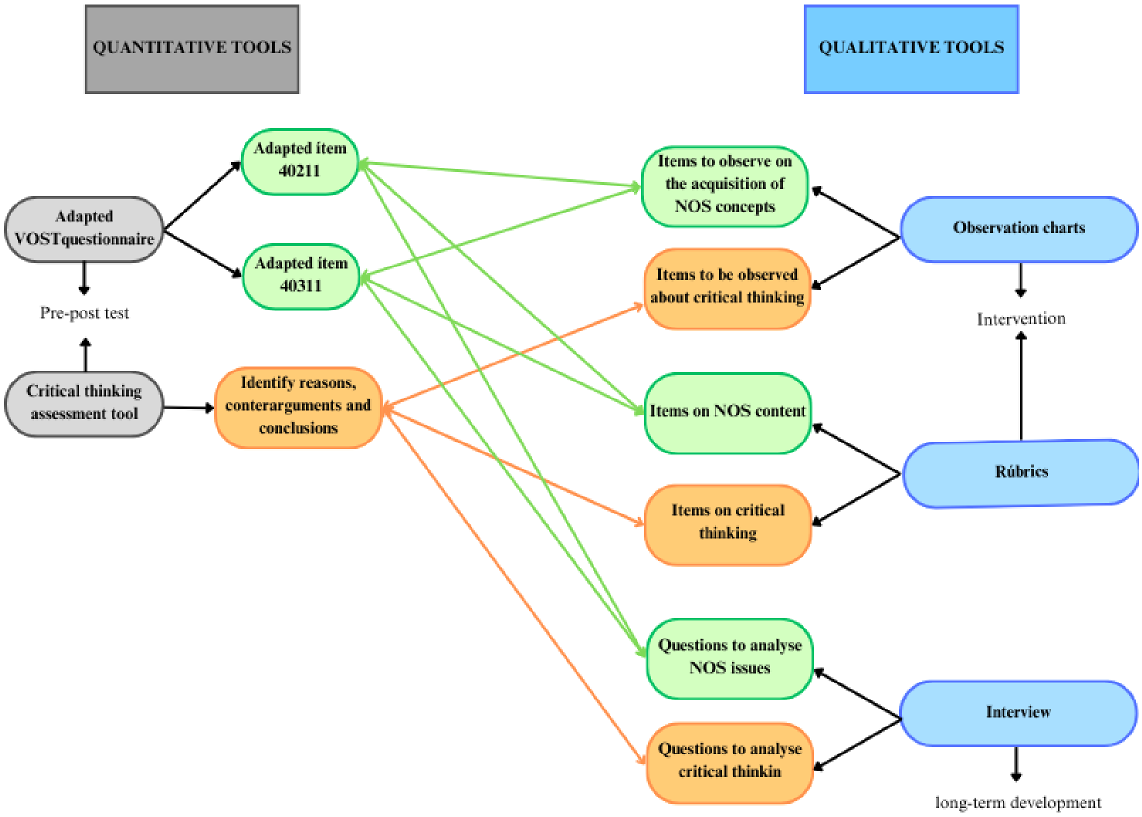

Figure 8. Relationship between research tools

Method of analysis

The quantitative analysis of the data was performed using the statistical software tool SPSS 24. The Wilcoxon signed-ranked test was used to compare pre-test and post-test results, while the Mann-Whitney U test was used to compare significance in improvements for each group in contrast to the control group. In addition, effect size was measured to convey a fuller meaning of the results related to the search for significant differences.

As for qualitative analysis, a system of categories was implemented to analyse observation charts and interview transcripts (Table 2). The system was deductively based on Manassero and Vázquez (2019) for NOS categories and on Halpern (2014) for CT categories. The categories were designed to bring together qualitative and quantitative assessments for data triangulation. Student productions were analysed using the rubric described above.

Table 2. Categories for qualitative analysis

Categories		Subcategories
NOS improvements	Societal impact of science and technology	40211. Decision making in scientific matters 40311. Compromise between the positive and negative effects of science and technology
CT improvements	Argument analysis	1.1. Use of reasons and counterarguments 1.2. Formulation of conclusions

Teaching intervention

The TLS focuses on energy as curriculum content, tailored to match the developmental stage of 10- to 12-year-olds, injected with explicit CT and NOS contents (Acevedo, 2009; Tenreiro-Vieira and Vieira, 2021) (Table 3). It is therefore a pedagogy where the aim of teaching focuses on developing argumentation for particular positions, without the requirement that students accept a predetermined position, but which forces them to reflect on the content of the content (Brock and Park, 2022).

Table 3. Content of the TLS

	Activities	NOS content	CT content	Curriculum content
Session 1	Introduction (20'): 'Produce, classify, connect, elaborate' + reflection and discussion. Content presentation (45'): 'Listen/ask' + discussion. Consolidation (45'): 'Discuss with your partner' + classroom discussion.	Decision making in scientific matters. Dependence on the implementation of new technology.	Argument analysis.	Energy: Definition, properties (conservation, degradation, transformation, transfer and transport), types of energy.
Session 2	Introduction (20'): 'Words, phrases and ideas' + reflection and discussion. Content presentation (45'): 'Listen/ask' + discussion. Consolidation (45'): 'Discuss with your partner' + classroom discussion.	Decision making in scientific matters and compromise between the positive and negative effects of science and technology. Dependence on the implementation of new technology and control of technological development by individuals.	Argument analysis.	Sources of renewable energy and sources of non-renewable energy.
Session 3	Introduction (20'): 'Look, think and wonder' + reflection and discussion. Content presentation (45'): 'Listen/ask' + discussion. Consolidation (45'): 'Discuss with your partner' + discussion.	Decision making in scientific matters and compromise between the positive and negative effects of science and technology. Dependence on the implementation of new technology and control of technological development by individuals.	Argument analysis.	Fracking (introduction to the; environmental and economic impact).

Based on Ortega-Quevedo et al. (2022b, 89).

Note: it is important to clarify that each teacher adapted the time of each session to the needs of the classroom, the minimum duration per session being 60 minutes.

Each TLS session was divided into three parts: implementing thinking routines (Ritchhart et al., 2014) for the activation of prior knowledge, which is materialised and shared; engaging in dialogue with the students to present the content and kindle their interest by relating the topics to the world around them when answering their questions; and answering questions – e.g., 'Is energy necessary? Why?', 'Do you think the benefits of renewable energy sources make up for their drawbacks?' – in small groups and then having classroom discussions.

Results

NOS: Decision making in scientific matters

The results of the analysis of item 40211 show that the median for the experimental groups is less in the pre-test than in the post-test phase (Figure 9). This trend can also be observed for individual groups (minimum: -1; maximum: 1).

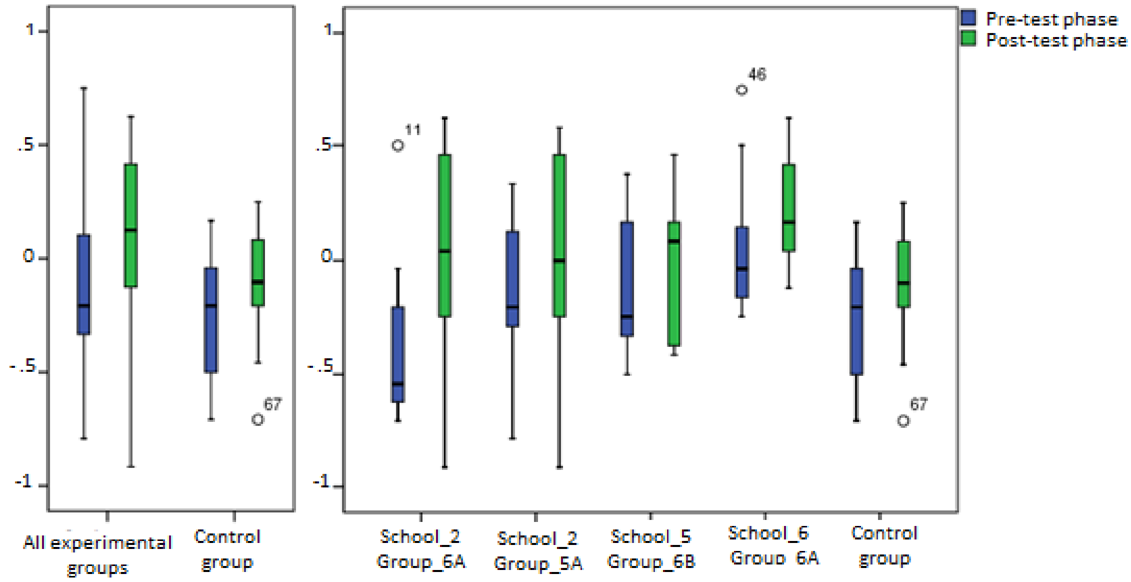

Figure 9. Boxplot for item 40211 of the adapted VOSTS

The Wilcoxon signed-ranked test was used to test the significance of the differences in pre-test and post-test results for each group. With a p-value of .001, it may be concluded (z = -3.287; r =-.4) that the difference was significant for all experimental groups. When broken down, the experimental groups School_2_Group_6A and School_6_Group_6A showed p-values of less than .05 (r < -.3 compared to the groups with significant differences where we found r = -.6). In the case of the control group, the p-value was .14, therefore there are no significant differences.

Then, the Mann-Whitney U test was used to see if the improvements in each group were significant as compared to the control group. First, it was applied to the experimental groups together, as opposed to the control group, in this case we obtained significant results (U= 283; p = .014; z = -2,45; r = -.3). When comparing the individual group, it was observed that the difference was significant for School_6_Group_6A (U= 50; p=.000; z = -3,542; r = -.7).

The analysis of the observation charts shows that the students began to think about NoS contents (decision making in scientific matters) in session 2, especially in the consolidation discussion. In the case of School_2_Group_6A, the class was engaged in a lengthy discussion, thinking about the answers given to the questions in the workbook and rephrasing those that were too simple (inadequate statements or scientifically implausible ideas) or plausible enough and so scientifically acceptable, e.g. 'The people and the President' was reformulated as 'The people who understand these matters, along with scientists' (source: observation chart notes on student answers). In School_2_Group_5A, all the small groups in the classroom were given the chance to share their hypotheses about the questions asked in the consolidation activities (e.g., 'Who should decide on the energy resources we use in Spain?'). However, some of the hypotheses were scientifically incorrect and failed to be reformulated, which led to statements that were generally plausible about who should make decisions in technological and scientific matters, such as 'Scientists and the people' or 'Politicians should listen to scientists', along with naive remarks like 'Not politicians, for they would choose the cheapest solutions' or 'We should all be able to share our opinions if we are to change things' (source: observation chart notes on student answers). In the case of School_5_Group_6B and School_6_Group_6A, the topic was not discussed beyond the answers to the questions asked in the workbook. However, School_6_Group_6A engaged in a very dynamic discussion of the workbook exercises, with statements considered plausible or accepted in science, such as 'Individuals who have learnt from scientists.' In School_5_Group_6B, on the other hand, there was not so much time for discussion and the class did not explore the full dynamics (no writing in the workbooks, no rephrasing, no reconstruction of knowledge, merely verbal exchanges).

These results are consistent with the analysis of student productions. When answering the questions about decision making in scientific matters, the students gave answers that were correct (24 percent of the workbooks analysed, e.g., 'Scientists and individuals who have learnt about this'), plausible (48 percent, as in 'Politicians, who should do what scientists say is good') and naive (28 percent, such as 'TheGovernments [sic]; they are in charge'). Therefore, overall, the following results can be drawn from the assessment rubrics: 28 percent were rated as low-level; 48 percent as average and 24 percent as high-level. This means that 76 percent of the groups avoided naive answers and stated scientifically accepted views (Vázquez and Manassero, 2012), which shows a certain degree of development of NoS knowledge.

The six workbooks of School_2_Group_5A contained no high-level grades, three answers classified as average and three low scores (naive answers). This is consistent with the limited improvement observed in the quantitative analysis. When compared to groups with significant improvements, such as School_2_Group_6A (4 average and 2 high grades), it can be seen that rubric's markers of quality are higher for the latter, which is consistent with the quantitative analysis.

In the case of School_5_Group_6B (remember that the workbooks are group workbooks.), the improvement was not significant in quantitative terms, which the observation and the analysis of student productions revealed was related to the disruption of the classroom dynamics. Since no time was spent rephrasing the answers and reconstructing the knowledge after the discussion, especially in consolidation activities, the students' output did not improve as expected.

Finally, in the follow-up interviews one month after the intervention, the students were asked if their views on the subject had changed. Most said they had not given the topic any thought before the intervention. The students with an advanced level of learning achievement gave scientifically adequate opinions, while the views of average and basic-level students were somewhere between adequate and plausible, although the statements by basic-level students were tentative and poorly justified (Vázquez and Manassero, 2012). A few examples are shown below.

3.F.6.6A.A: 'Yes, because before I thought the Government should decide and now, I think they must listen to other people, so they've changed.'

44.M.2.6A.M: 'Not really, no, maybe a little. Now I know it should be scientists and governments, a little bit, and individuals who know about this.'

NOS: Compromise between the positive and negative effects of science and technology

The results of the analysis of item 40311 of the adapted VOSTS questionnaire are shown in Figure 10. The average score and the quartiles of the experimental groups taken together were slightly higher in the post-test phase than in the pre-test phase. Taken individually, the experimental groups followed a similar trend, except for School_2_Group_5A, which had lower scores.

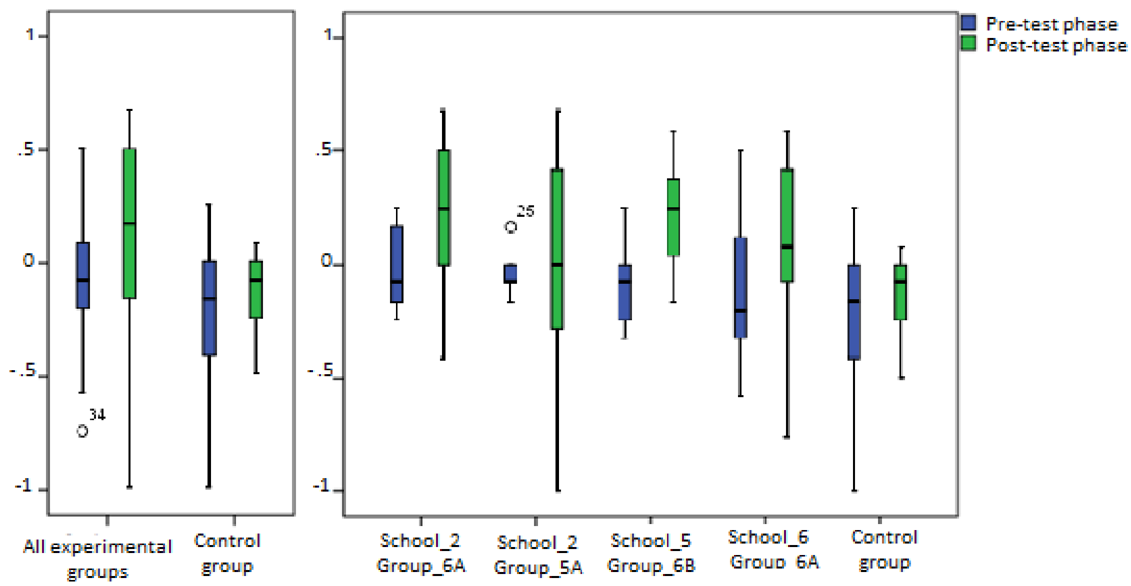

Figure 10. Boxplot for item 40311 of the adapted VOSTS

Again, the Wilcoxon signed-ranked test was used to test the significance of the differences in pre-test and post-test results. With a p-value of .003 (z = -2.953; r = -.4), the test showed the differences were significant for the experimental groups taken together. As to individual groups, the differences were significant for the groups in schools 5 and 6 (p =.027; z= -2.213; r = -.7 and p =-.006; z= -2.738; r = -.6, respectively). For the control group, the test revealed an absence of significance (p = .48; z = -,714; r = -.17).

When comparing the results of the experimental groups to those of the control group, the Mann-Whitney U test showed that the improvements of the former were remarkable (U = 204; p = .003; z = -2.937; r =-.35). Individually, all class groups except School_2_Group_5A had p-values of less than .05 with r between 0.44 and 0.61.

The observation charts showed how the students became aware of the positive and negative effects of science and technology in the consolidation discussion about sources of renewable and non-renewable energy. These concepts were taken up again in the consolidation activities dealing with fracking. According to the observations, the groups in schools 5 and 6 did not include explicit teaching in the ‘Listen/ask’ activity but devoted part of the consolidation discussion to this topic, rephrasing the naive answers and bringing them closer to scientifically accepted views. As a result, the most common statements included: ‘There are bad things that can’t be controlled; there are things that are both good and bad’ (observations from school 6) and ‘There has to be a compromise between the positive and the negative effects. Take solar panels: they have to be in a place where they can supply enough energy and where they do not do too much harm’ (observations from school 5). The_School_2_Group_6A teacher took a similar approach, with less explicit work on the contents but still redirecting the discussion. However, some of the statements uttered in this group were not adequately rephrased, especially those in connection with the lack of balance in renewable versus non-renewable sources of energy: ‘There’s no balance because non-renewable sources can’t be used again, so you’ve spent a lot of money on something you can’t use more than once’ (observations from School_2_Group_6A). In School_2_Group_5A, the teaching was not too explicit and the discussion was not lengthy, but the most common statements were scientifically correct: ‘There has to be a compromise because if what’s bad is too bad, then it’s not worth it’ (observations from School_2_Group_5A).

The observations matched the activity results: samples of this kind of discourse were found in the exercises done by the participants in the experimental groups in session 2, when the students had to share their views on the positive and negative effects of introducing new technologies or new scientific knowledge. In this regard, 15 percent of the workbooks analysed contained high-level answers; the answers in the 77 percent of the workbooks were classified as average; and 8 percent showed low-level answers. Regarding the answers with low scores, it must be pointed out that even though they do mention the negative aspects of science and technology, they merely list the positive and negative effects, without applying this knowledge to the main reflection. Also, it should be observed that the answers in the workbooks from School_2_Group_5A were all rated as average, a fact that contrasts with the quantitative results, where the median showed a slight decrease.

Finally, in the follow-up interviews, the students were asked if they had changed their views on the compromise between the positive and negative effects of science and technology. Most of them said they have not thought about this issue before the intervention, and everyone, irrespective of their level of learning achievement (even the students in School_2_Group_5A, the only group with poorer post-test results), insisted on the need for a compromise in this regard. The interviewees with a more advanced level of learning achievement expressed themselves more properly and justified their views with arguments that came closer to the scientifically accepted (Vázquez and Manassero, 2012). A few examples are shown below.

3.F.6.6A.A: ‘No, because it’s always been positive. Everything has… a… convenience and an inconvenience. Because when you make solar panels, for instance, to produce solar energy, making them causes pollution, but then it’s less polluting.’

44.M.2.6A.M: 'Well, yes, because if something is... too harmful... then... it'll end up having too many negative effects for someone or something and things could get ugly. (And had you thought about this before?) I'd never thought about this.

CT: Use of reasons and counterarguments; formulation of conclusions

The results of the analysis of argument analysis skills can be seen in Figure 11. The values of both the median and the quartiles were higher in the post-test phase for the experimental groups, both together and individually, except for School_2_Group_6A (minimum: 0; maximum: 4). On the contrary, the control group showed no variation between the pre-test and the post-test phases.

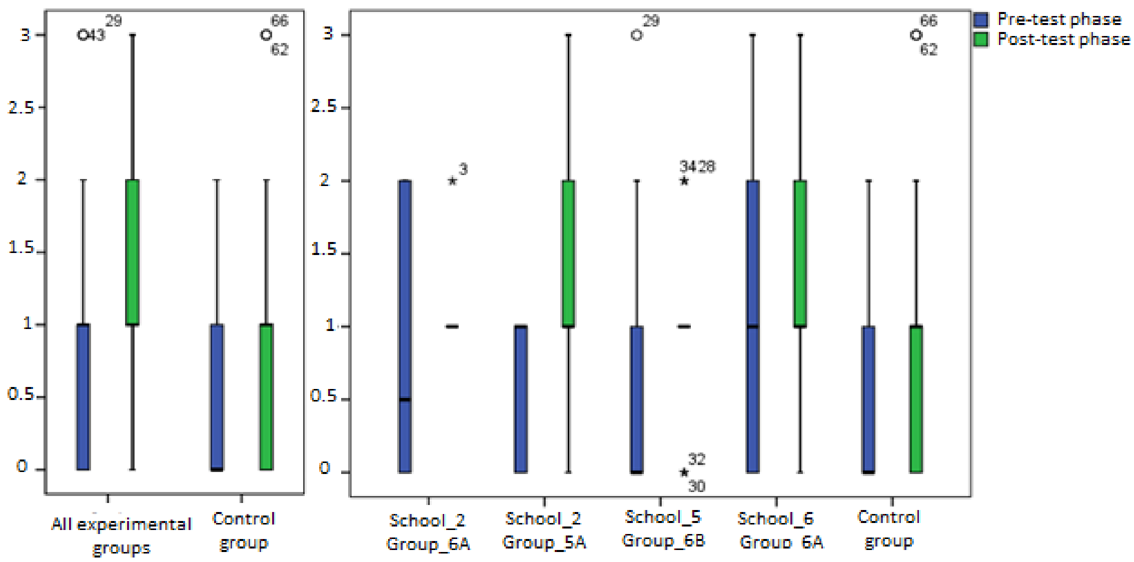

Figure 11. Boxplot for the argument analysis

The Wilcoxon signed-ranked test was used to test the significance of these observations. With a p-value of .003 (z = -2.909; r = -.4) for the experimental groups, it can be said that the difference is significant. When broken down, the experimental groups from schools 5 and 6 showed p-values of less than .05 (r =-.1 and r =-.27 respectively), which means there was significant improvement after the intervention. In the rest of the group, higher r's between -.51 and -.7 are obtained. As to the control group, there were no significant improvements (p = .56; z = -.587; r = -.1).

Then, the Mann-Whitney U test was used to see if the improvements in each group were significant as compared to the control group. When comparing the experimental groups to the control group, the p-value was .013 (U= 286; z = -2,478 r = -.3), which means that there was significant improvement in the CT skills under study. Broken down by groups, the p-values were less than 0.05 for School_5_Group_6B (U= 31; p = .006; z = -2.786; r = -.88) and School_6_Group_6A (U= 95; p = .035; z = -2,178; r = -.5).

The observation charts show how explicit work on argumentative skills began in session 1, describing the various parts of an argument. This was done in all class groups, when the teachers explained the outline of the exercises in the first consolidation activity. Building on this, then the teachers encouraged the students to use subject-specific vocabulary in both introduction and consolidation activities. However, not every teacher encouraged the use of argumentative skills for the discussion. The two teachers in school 2 promoted interaction between the students and encouraged the students to endorse or rebut their classmates' arguments instead of just reading their written answers. On the other hand, the teachers in schools 5 and 6 were less successful in promoting interaction. The following interesting facts were also observed:

- The argumentative discourse observed in school 6 was aggressive and poorly based on evidence. Discussions were often settled without reaching scientifically adequate conclusions.
- In school 5, the development of argumentative skills was somewhat hampered in the final session, as content integration – the climax of the process – was too overwhelming for the students to feel at ease. This resulted in more individualistic, less contrasting participation.
- In School_2_Group_5A, the discussions were smooth and dynamic, with a high level of interaction and argument analysis.
- In School_2_Group_6A, the students were encouraged to reply to some questions only, and the connections between the arguments used in the discussion were not always shown.

The rubric-based assessment of the workbooks showed that there had been improvement in argumentative skills, especially between the first and the second block of activities (Figure 12). While for session 2 the workbooks contained 69 percent average and 8 percent high-level productions, for session 3 the percentages were 95 for average and 5 for high scores. This means that most students can be placed in the average level of achievement and the progress stops there (no progress to the advanced level). Since the workbooks from school 5, which had high scores in the previous session, could not be assessed, the data were not available to add to the advanced level.

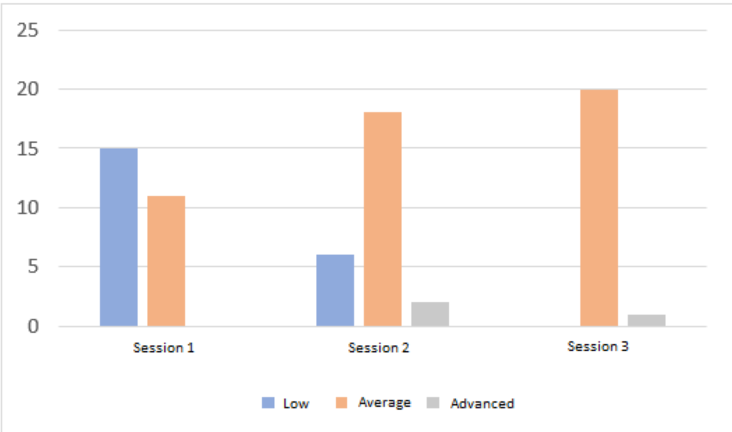

Figure 12. Argument analysis assessment results by achievement levels and sessions

Finally, in the follow-up interviews, the students were asked if they remembered the main argument in the video shown in session 3. They all said they did remember the main arguments in the video, although the arguments they said or showed they remembered most clearly were those against fracking. In this case, there were no significant differences across levels of achievement. Some of the students' statements illustrating these findings are shown below.

49.M.2.6A.A: 'I don't quite remember, but I could tell you some of the arguments. First of all, it's both good and bad. It can't be wonderful and it can't be terrible either. But there's an issue with the environment. They're using it for this thing, fracking; they're exploiting the environment and that's not good. There's no good reason behind fracking, just profit; there aren't many good things about fracking. But it's also true that without fracking, we'd have run out of oil and we couldn't drive cars now, for example. So, there's something good about it, then. There is always something good. So, we have to go back to the idea of a compromise that we mentioned earlier.'

30.M.2.5A.B: 'Yes. There were people who said fracking polluted the environment, but then there were others who said it was a technique used to study things and produce energy. Farmers were against fracking too… as… it could cause earthquakes… but I think politicians will be ok with it because it's cheaper and it means not having to buy non-renewable energy from other countries but producing it ourselves, which would be cheaper and would help us move forward in the things we do.

Discussion of results

In order to analyse the students' progress in decision making in scientific matters, the findings of this study were compared to those in Ortega-Quevedo et al. (2022a), a study with similar contents and constructs (items 40211 and 40311 of the VOSTS questionnaire; CT skills such as argument analysis and verbal reasoning; and the subject of energy as carrier content), albeit with differences in the teaching process: (1) a TLS sticking strictly to the classroom syllabus and highly explicit teaching, unfolding in a very short period of time, and (2) a single teacher implementing the TLS in all class groups.

The scores in the attitude scale, the higher obtained between the pre- and post-test phases (.35 in contrast.22) and the assessment of student productions (21 percent advanced, 58 percent average and 28 percent basic workbooks) show better results than those obtained by Authors. This means that, in this study, a higher number of students reached the highest level of learning achievement. This enables the conclusion that, even in short periods of time, explicit teaching leads to greater improvement in the attitude scale and a lower number of workbooks containing naive views on the subject under study. On the other hand, less explicit teaching with more time for reflection leads to a higher number of advanced-level workbooks. These findings qualify Acevedo's conclusion that 'explicit and reflective NOS teaching across learning contexts is more effective than implicit teaching when it comes to improving NOS understandings in students and teachers' (2009, 366). Is also contrasted with the results presented by Voss et al. (2021), contributing new information to the line of research. For the aspects of NOS considered in this study, equally good results can also be obtained with less explicit teaching over longer periods of time.

In addition, the study's results were also compared to those obtained by Porras et al. (2020), who implemented a TLS among 15- to 17-year-old students, aimed at improving their understanding of this and other topics. The measurements in Porras et al. showed overall values of .023 for the pre-test phase and -.003 for the post-phase test (.026 decrease), in contrast to the increase shown in the present study.

As to the improvement in the understanding of the need for a compromise between the positive and negative effects of science and technology, the results in Ortega-Quevedo et al. (2022a) showed variations along the learning process similar to those found for decision making in scientific matters.

Regarding the initial attitude scale medians, whereas for the pre-test phase they are higher in Ortega-Quevedo et al. (2022a), for the post-test phase they are similar. This means that the increase is higher in this study (.18in contrast to .14). Similar results can be observed in the rubric-based assessment of the students' workbooks (92 percent rated as average and 8 percent low scores in Ortega-Quevedo et al., 2022a, in contrast to 15 percent high scores, 72 percent average and 8 percent low scores in this study). As these results show, in Ortega-Quevedo et al. (2022a), explicit teaching succeeded in driving the students away from naive views. However, less explicit teaching over longer periods of time can also achieve good results in the rubric-based assessment, as shown by the constant percentage of low-level answers and the increase in high scores. Once again, these results qualify Acevedo's conclusions about explicit in contrast to implicit teaching (2009).

When compared to the data in Porras et al. (2020), the improvement shown in this study is not as significant (.18 in contrast to.075, from -.062 in the pre-test phase to .013 in post-test measurements). However, the trend is the same.

Regarding the development of argument analysis skills, the comparison with the study by Ortega-Quevedo et al. (2022a) shows similar variations for the teaching of NOS concepts. As to quantitative data, since the assessment tools where different, the results of the two studies had to be weighed. The attitude scale shows a higher increase in this study (.162 in contrast to .144). As to the rubric-based assessment, the initial scores were lower in this study (4 percent advanced, 61 percent average and 35 percent basic, as compared to 15 percent advanced, 64 percent average and 21 percent basic). The assessments of session 3 show there was progress in both studies, with higher scores in Ortega-Quevedo et al. (2022a).

All these data show that less explicit teaching over a longer period time leads to greater improvement in quantitative terms but less apparent success according to the qualitative analysis, with a lower number of students reaching the advanced level of achievement.

When compared to Porras et al. (2020), a study using everyday situations that match those in the thinking skills assessment tool used in this study, one of them matching the topics and skills studied here, the students were less accurate when it came to identifying the parts of an argument in this study, but they made greater progress after the teaching intervention.

In summary, the infusion of PC skills together with NdCyT content contributes to improving the development of thinking and conceptions about NDCyT (Torres and Solbes, 2016; Vázquez and Manassero, 2018; Manassero and Vázquez, 2019). Therefore, the results allow us to infer that connection detected by scientific evidence between critical thinking and scientific thinking (Erduran et al., 2006; Jiménez-Alexandre and Puig, 2012; Porras et al, 2020; Quijano et al., 2014; Tenreiro-Vieira and Vieira, 2021; Torres and Solbes, 2016, 2018; Vega and Callejas, 2020; Zeidler, 2003).

Conclusions

From the results of the study, it can be concluded that the development of CT skills (argument analysis) and NOS concepts (decision making in scientific and technological matters, and the need for a compromise between the positive and negative effects of science) improve after the implementation of a TLS. The results, in line with those of previous studies in basic education (Acevedo et al., 2017; Porras et al., 2020) and teacher training (Cobo-Huesa et al., 2022; Cullinane and Erduran, 2022; Valente et al., 2024), are a contribution to the scientific corpus in the field, where more data are needed for basic education.

The analysis of the study results shows an improvement in the students' views on the positive and negative effects of science and technology, both when comparing different moments in the research project and when contrasting the experimental groups with a control group. Likewise, the study shows that a TLS can contribute to the development of NOS concepts by resorting to less explicit teaching and reflection over longer periods of time if the teacher in charge is adequately trained in the topics being discussed. This leads to the conclusion that reflection and argumentation are key to the development of NOS concepts (Khishfe, 2022).

As to argument analysis skills, the study results show improvements when comparing the performance of the experimental groups before and after the TLS, and when comparing the experimental groups to the control group. In this aspect, too, less explicit teaching with more time for reflection leads to improvement, provided that the other basic elements of the teaching model the TLS is based on, e.g., making thinking visible and training assessment, are also present.

For future research based on interventions in classrooms at these levels of education, it would be useful to address the limitations identified in the present study. These include, firstly, the limited time frame of the intervention, which, if it had been more extensive, could have led to more favourable results. Secondly, the work of the teachers, despite receiving the same training, is different and may therefore affect the results obtained. Finally, it is considered necessary to apply the learning situation in other contexts in order to contrast or generalise results.

Finally, the results of this study suggest that providing educators with a teaching design whose implementation, with adequate training, leads to improvement in NOS understandings and to the development of CT skills, as well as in curriculum implementation, does not mean ensuring accuracy and good results across contexts, as the application and the success of the teaching design are dependent on teacher style and emphasis on specific aspects. However, even taking different teaching styles into consideration, it does have a positive impact on student development. Therefore, it could be interesting to further research on the improvement of NOS understandings and CT skills among basic education students to reach optimal development throughout this educational stage.

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