Use of socio-scientific issues in order to improve critical thinking competences

Jordi SOLBES[*], Nidia TORRES, and Manel TRAVER[*]

Universitat de Valencia[*]

Universidad Pedagógica y Tecnológica de Colombia, COLOMBIA

[*]Corresponding Author's Email: nidia.torres@uptc.edu.co

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Abstract

This article analyzes the implications of the use of socio-scientific issues (SSI) in a series of critical thinking competences. For this, a didactic intervention with 3 SSIs is carried out, developed during 16 weeks, in which there were 56 students who participated in a program of education in the sciences. A quasi-experimental design was used and there is a comparison of the pre-test and post-test to describe the

influence of the intervention. The test information was assessed from an analysis qualitative and quantitative that compares the type of participant responses once the intervention. The study allows us to see the incidence of the SSIs in aspects, such as the acknowledgement of science as a social activity, the questioning of information, the multi-dimensional approach to the sciences, and the making of ethical judgments and fundamental decisions. In this way, this research demonstrates how the SSis for assuming scientific issues with social implications, are a possibility to motivate and promote the development of critical thinking in students of teacher training in Natural Sciences.

Keywords: competences, socio-scientific issues, scientific education, critical thinking.

Introduction

At present, the development of critical thinking is relevant as, in many cases, questioning is avoided, which impedes distinguishing the veracity of arguments. Therefore, the existence of a non-critical attitude does not allow for one to have the elements to make well-supported decisions that lead one to act accordingly. For that matter, one of the challenges in training processes is related to the development of teaching strategies that promote critical thinking, (Torres and Solbes 2016).

With respect to this, many studies of psychology, such as the ones carried out by Ennis (1987); Facione, Facione and Giancarlo (2000), and Zoller and Pushkin (2007) have characterized critical thinking as a rational, logical, reflexive and evaluative way of thinking. Ennis (1987), who was a pioneer in studying the topic, defines it as that “way of thinking that decides what to do and what to believe in” (p. 10) and others like Halpern (2006) have related it with the development of abilities, for example interpretation, argumentation, probability, problem-solving and decision-making. But, from other fields such as philosophy, contributions regarding this way of thinking are highlighted in order to maintain a sceptical attitude regarding the dominant dogmas and discourses, and to expose the consequences of being led by unidirectional discourses which do not allow one to understand multiple cultural and social phenomena (Habermas, 1971; Marcuse, 1991; Adorno and Horkheimer, 2002).

Critical thinking has not only been the object of reflection for philosophy and psychology, but also for critical pedagogy, which describes teaching as a process of individual and collective emancipation in order to transform today's society (Giroux, 1988; Freire, 1996), and for the teaching of science, based on the history and the epistemology of science. For example, Popper (1970) highlighted the importance of the formation of critical thinking in a university environment. Therefore, from the contributions made by philosophers of science and scientists, said way of thinking has fostered the formulation of judgments based on evidence through which their validity can be proved. Critical rationalism and a sceptical attitude should also be applied to the dominant dogmas and discourses (Marcuse, 1991). From this perspective, one of the main characteristics of this way of thinking has been the possibility to question and establish counter-positions, in the presence of opinions that have been taken for granted. At the same time, the epistemological approach (Popper, 1970; Haack, 2007; Kuhn, 1962) has contributed to questioning the scientist concept of science which it considers to be correct, problem free, and unquestionable.

The contributions of the history and sociology of science show that science is methodologically critical, but for some of their elements to be considered as critical thinking, and to act socially as such, socio-scientific issues (SSIs) have to be addressed. At the same time, proving a hypothesis is a necessary condition of critical thinking, but it is not enough (Torres and Solbes, 2016). Although several research projects have shown the effects of promoting scientific argumentation from the use of SSIs (Topcu, 2010; Albe, 2008), therefore, this work shows how work shows how (SSIs) can contribute to develop critical thinking in a group of students of a science teacher training program.

As SSIs involve scientific topics that have a social incidence (Topcu, 2010; Day and Bryce, 2011; Çalik and Coll, 2012), they favour learning processes and facilitate the creation of spaces for the debate, discussion, and defense of points of view (Passmore and Svoboda, 2012), relevant aspect not only for promoting scientific argumentation, writing and defending points of view, (Solbes and Traver, 2003), but also for the development of critical thinking (Jiménez-Aleixandre, 2010; Torres and Solbes, 2016). SSIs can create an opportunity to participate in scientific reasoning, writing and defending points of view, and participating in counter-arguments on subjects disseminated through the media. They can also be useful to fulfill the objective of education for the citizenry through scientific education (Barrue and Albe, 2013).

Thus, SSIs are a social practice that implies the exercise of critical thinking in classroom scenarios that allow the students to understand the meaning of scientific concepts and to what extent they can be used for social issues (Dawson and Venville, 2010; Tytler and Prain, 2010). From this perspective, taking into consideration the contributions of philosophy, psychology and the teaching of the science, in this research project critical thinking is seen as a set of "capacities that people have in order to structure their own way of thinking which allows them to distinguish the veracity of arguments, take a stance in view of social situations in order to have an active role in cultural and scientific decisions taken based on social responsibility" (Solbes and Torres, 2012, p. 248).

But, how is the incidence of SSIs in the development of critical thinking assessed? With respect to this, we have considered several theoretical perspectives (Ennis, 1987; McMillan, 1987; Facione et al. 2000; Halpern, 2006) that associate critical thinking with abilities, ways of thinking or competences, and considering that the concept of competence involves both the above, because of their complexity and that they require the articulation of skills, attitudes, and dexterities. In this sense, the authors of this article see critical thinking as a set of competences and affirm that SSIs are built into contexts so as to practice *critical competences*, that according to diverse authors could be: I. Understanding the nature of science (NoS) as a human activity and with multiple relations with STS (Lederman, 1992; Solbes and Traver, 2003); II. The analysis and questioning of information, rejecting conclusions that are not based on proof, detecting argumentative fallacies (McMillan, 1987; Yager, 1993; Vieira, Tenreiro-Vieira and Martins, 2010; Osborne, 2010); III. The comprehensive study of SSIs involving scientific, technical, cultural, economic and political dimensions (Solbes and Vilches, 1997; Sadler, 2004); IV. Carrying out ethical evaluations of the impact of technological and scientific development (Sadler and Zeidler, 2004) and V. Making decisions on fundamental aspects in the development of critical thinking and acting consequently (Ennis, 1987; Nickerson, 1994; Facione et al. 2000; Halpern, 2006; Osborne, 2010; Aikenhead, 1985). Said competences were considered in this research and are presented in Table I.

Thus, the study responds to the following research question: How and to what extend did SSIs contribute to the development of critical thinking competences? Its main objective was to analyze the implications of SSIs in the development of critical competences in students from a science teacher training program showing the pre-

test and post-test results to the research. At the same time, several research studies have shown that students from different levels, from primary (Malamitsa et al., 2009) to university students (Ekahitanond, 2013) can develop projects aimed at fostering the abilities of critical thinking.

Methodology

Participants

This research was carried out in the year 2012 with 56 students from the sixth semester of the Bachelor's Degree in Natural Science and Environmental Education of the Universidad Pedagógica y Tecnológica de Colombia (UPTC, by its acronym in Spanish), which is a public university. In the near future, these students will teach Physics, Chemistry and Biology in the public education system (to 12-18 year olds). The ages of the participants range from 19 to 24 years of age, and 11 are male and 45 are female. In this study, it was considered that the group that is taking said subjects is appropriate for carrying out the intervention, given that they have already seen 60% of the disciplinary and pedagogical contents of the program. Therefore, it can be inferred that they have a good understanding of the scientific contents involved in the activities and have the necessary elements to apply what they have seen in class to different situations of their daily lives. Oral consent was requested from all participants in order to take part in the research and anonymity was guaranteed through the assignment of a numeric denomination.

Didactic intervention

The research mentioned was carried out over a period of 16 weeks, in three phases: *the diagnosis*, which involves the pre-test with regard to the privatization of a power station, which was realized in a 90-minute session; *the intervention* in which 3 sequences of activities about critical thinking and SSIs were carried out, all in 120 minute sessions. In detail, in the first session of the intervention a study related to scientists was done, in which, due to the scientific themes and the SSIs that were dealt with, problems of a different nature arose: ideological, political and economic. The second session was about coffee consumption and the use of chemical additives in its industrialization. The third was about the use of glyphosate for the eradication of illegal crops. They are all open activities that show the multiple dimensions of

science (its relations with technology and society, STS) contextualized in Colombia (except for the activity of the scientists, which shows the universal nature of SSIs). In them, the validity of the arguments is questioned, and conclusions rejected which are not based on proof, argumentative fallacies are detected and the credibility of the sources is assessed. Ethical assessments and judgments are made. Supported decisions are reached and actions are proposed. Finally, there is a phase of *final assessment* referred to the application of the post-test. It is the same as the pre-test, but about different topics from the ones dealt with in class (scientists, glyphosate, coffee additives), so as to confirm that the improvement in the students is the result of them acquiring the competences of critical thinking, and not to the fact that they know more about power stations and their privatization. In addition, this questionnaire was answered 4 months after the pre-test, which guarantees that the improvement is not a consequence of what they remember.

Instruments

A test was designed that allows for the characterization of critical competences in the SSI environment. The test was used at the beginning and at the end of the intervention, and it deals with the privatization of the electrical power company of the region of the university, so it is a discussed in-context situation. The instrument was applied over 90 minutes, individually, and it was composed of three aspects with 11 questions, grouped in 3 sections and with a length of 2 pages. Said questions can be seen in Table 1, grouped by critical competences.

Section "i" is related to the generation of electricity, and its aim is to question how electrical energy is generated. A scheme is presented that shows the generation of power. From the figure, students are requested to describe the process by which this energy is generated.

Between the items of section "ii", titled *Electricity in Colombia*, the current state of electricity in Colombia is presented in relation to the energy produced from water, thermal and wind sources. The main objective of this section is that the students question the information presented about the effects of hydroelectric plants on the environment and society. In the last section, *the privatization of electricity companies in Colombia*, the instrument presents the current state of a social phenomenon in the country related to the privatization of public companies. Fragments published in

some newspapers were presented, with statements from different actors, which include political, social and economic aspects.

To assess the internal coherence of the items of the instrument, the Cronbach alpha was calculated with the data collected from a pilot group of 26 students. The value of the Cronbach alpha is 0.8 and, therefore, higher than the value 0.7, which indicates the internal consistency of the questionnaire used. In the same way, the median variance extracted was superior to 0.57, which indicates that the construct shares more than half of its variance with its indicators.

Data analysis

For the analysis of the data collected from this instrument, there were two levels of interpretation. On the one hand, the percentage of students that responded to the questions was calculated. The result accounts for the critical competences established in the framework of the research (Table I). There was also a textual description of the answers given by the participants.

In this article, the comparison between the pre-test and post-test results were presented, in order to describe the influence of the intervention, that is to say, the incidence of SSIs in the development of the competences of critical thinking.

Table I. Competences of critical thinking and questions from the test

CRITICAL COMPETENCES	QUESTIONS FROM THE PRE-TEST
I. To understand the nature of science as a human activity with multiple relations with technology, society, and the environment.	*iii.1. Do you identify problems in what was previously described? If your answer is yes, which ones? Why?*
	iii.2. Do you consider that the situation previously described may be the object of reflection of the sciences? *Yes____ No ____* *If your answer is yes, in what aspects and why?*
II. To be informed about the topic, not to be limited to the dominant discourses; to be aware of alternative positions; to question the validity of the arguments, rejecting conclusions that are not based on proof; to detect argumentative fallacies; to evaluate the reliability of the sources, taking into account the underlying interests, and to create well-supported arguments.	*ii.2. Do you agree with the following: It is affirmed that hydroelectric plants do not cause pollution; they help to stop the emission of CO2 and do not have an impact on the environment. What has been the impact of hydroelectric plants on the environment and society? And that of thermal plants?*
	iii.4. Do you agree with the method of production of electricity in the department of Boyacá?

	iii.5. What controversies or scientific disagreements related to the production or use of electricity have taken place?
III. To study the socio-scientific issue in a comprehensive way, in its complexity: in a way that scientific, technical, ethical, cultural, philosophical, social, economic, and environmental dimensions are involved.	*i.1.Observe the scheme that appears on the right and describe the procedure that is required to generate electrical power.* *i.2. What other procedures that allow a turbine to rotate in order to produce electricity do you know of?* *ii.1. How is electricity produced in Boyacá? Who produces it?*
IV. To value and make ethical judgements around the SSI, attending to their contribution in to the satisfaction of human needs and solving the problems of the world.	*iii.3. Do you agree with the privatization of EBSA? Why?*
	iii.6. Suppose that you are invited to a debate where the implementation of electrical power in the country is discussed. If your professional assessment o this matter was required, what would your statement be?
V. To build statements and conclusions that are duly supported, which lead to making well-supported decisions, to promote actions for the improvement of quality of life, and to be capable of transforming reality, by solving different situations at a personal, family and work level.	*iii.7. Based on the previous statement, what decisions would it be necessary to make, at a personal, work, and family level, with respect to the previous situation?*

The analysis of the information collected in the pre-test and post-test is carried out in the software *R version 3.0*. In order to determine the incidence of intervention with the use of SSIs in the development of competences of critical thinking, the results of the pre-test and the post-test are analyzed. At the same time, in order to verify the benefit of the intervention with the SSIs and its incidence in the post-test, the information obtained from both instruments is compared.

The analysis and classification of the answers provided by the participants to each one of the questions asked in the instrument was carried out from the comparison of the answers with a guide of responses for the instrument, elaborated by the authors.

By competence analysis

For each of the competences, there is a rating scale with the levels High, Medium, Low and Insufficient. For each level, a score is established according to the number of questions it contains, for example, competences II and III have 3 questions each, each one of which is evaluated as Adequate Explanations (3 points), General Explanations (2 points), Explanations Out of Context (1 point) and No Answer (0

points), (Solbes and Traver, 2003). To classify the answers in the rating scale, the researchers analyzed the answers independently and, afterwards, a consensus was established among them. Therefore, as said competences are composed of three questions each, which are rated from 3 to 0, their maximum score is 9 and the minimum is 0. In consequence, four levels can be defined according to the points obtained: High 9 and 8, Medium 7, 6 and 5, Low 4, 3 and 2, and Insufficient 1 and 0. If the competences are formed of 2 questions, as is the case of I and IV, the four levels will be: High 6 and 5, Medium 4 and 3, Low 2 and 1, and Insufficient 0.

In order to determine if there are relevant differences between the results of the pre-test and the post-test with regard to the percentage of students in each level, *Test Z* is used.

The changes that each of the students have experienced are described through 4x4 tables of contingency and, to analyze the differences, the *Stuart and Maxwell chi-squared test* is used,as there are ordinal variables of more than two categories (Cohen, Manion and Morrison, 2007).

Results

The results presented below are the product of a didactic intervention that consisted of the use of diverse SSIs, as was mentioned earlier. Therefore, in this article the pre-test and post-test results are presented, referring to the SSI on the privatization of a power plant, which allows us to indicate the influence of the SSI in the competences of critical thinking as shown in Table I.

The data presented in the following tables shows the percentages of students in each one of the levels and the *p* values found with the statistical Z. It is observed that the best values are registered in the High level, in competences II, IV and V with a *p* that equals 0.00. The post-test evidences an increase in the number of students reaching better levels, with a different level of difficulty to that of the pre-test. In the pre-test, values for competences in the following order were obtained III<II<V<IV<I. In the post-test, the values are ordered as follows: III<V<IV<II<I. It is observed that, in both tests, competence I is in first place and competence III is last.

Below, the results for each one of the competences are presented:

Table II. Comparison between the pre-test and post-test in competence I

Levels	High	Medium	Low	Insufficient
Pre-test	48.2	39.2	8.9	3.6
Post-test	91.0	7.1	1.8	0.0
p value	1.8·e-8*	6.8·e-6*	0.0*	0.0*

Asterisks represent significant differences

Competence I: *To acknowledge the nature of science as a social activity* obtains the best percentage in the post-test. It increased by 42.8% in the High level, with a p = 0.00 (lower than the level of statistical significance 0.05). This value shows that the students identify the problem of privatization and relate it with the study of science, as can be seen in the following answer, written by students E22 and E9 in the post-test when they are asked the question: Do you consider that the situation described as the *privatization of energy in Boyacá* can be an object of reflection of the sciences?

- Answer written by student E22 in the post-test: "Yes, because the reflections made in relation to science involve social, environmental, economic, political and technological aspects, and the above situation shows us how science has facilitated our activities but, at the same time, it creates a certain dependence on them, which has increased consumption policies, therefore, it has to be reflected on what science is producing in order to contribute to the environment."

- Answer written by student E22 in the pre-test: No answer.

- Answer written by student E9 in the post-test: "The privatization of the electricity company is a problem that involves various aspects, social and economic, for example the cost of electricity in Boyacá, the people who have worked for the company for years might be fired, and in the field of the science, which involves the social aspect, the following could be studied: the efficiency of the equipment used, the use of generators, and the invention of new technologies which are more eco-friendly and that are sustainable."

- Answer written by student E9 in the pre-test: "It is only a political problem. It is not related to science, as it does not study any phenomenon."

In their affirmations, the students improve their understanding of the nature of science after the SSI and start to acknowledge the social role of science.

Table III. Comparison between the pre-test and post-test in competence II

Levels	High	Medium	Low	Insufficient
Pre-test	7.1	42.8	42.8	7.1
Post-test	89.2	8.9	1.8	0.0
p value	0.0*	4.49·e-6*	1.11·e-9*	0.02*

Competence II: *To learn to question information* increased significantly from 7.1% to 89.2%. This indicates that the students became informed with regard to alternative positions and rejected the statements that were not completely valid. This is translated into a greater degree of information when questioning and not giving full credibility to some statements. For example, one of the questions for this competence presents the following statement: *It is affirmed that hydroelectric plants do not cause pollution; they help to stop the emission of CO2 and do not have an impact on the environment.* It is sought that the participants detect the fallacy and question the information presented. With respect to this, 30% of the students did not detect the fallacy in the pre-test and gave answers such as the following:

E1: "Yes, I agree with the above. I do not know of any environmental impact of great magnitude with reference to hydroelectric plants."

E24: "I agree with the fact that hydroelectric plants mitigate environmental pollution as they barely emit gases."
In the post-test, the students responded:

E1: "They produce an environmental, economic and social impact."

E24: "…although they are sources of renewable energy, they alter the reproductive cycle of aquatic fauna because of the construction of artificial ponds and alter the amount of water in rivers, their temperature and degree of oxygenation".

In the interventions of the post-test, the students indicate the environmental impact of hydroelectric plants on an aquatic and terrestrial level. As regards thermal plants, they mention the increase in polluting gaseous emissions. Their final affirmations account for the inclusion of the environmental dimension, which was comparatively limited in the answers of the pre-test.

Table IV. Comparison between the pre-test and post-test in competence III

	High	Medium	Low	Insufficient
Pre-test	5.4	38.0	42.8	14.2
Post-test	50.0	41.0	8.9	-
p value	6.0·e-10*	0.37	4.49·e-6*	0.001*

Competence III, referring to *the multidimensionality of science*, went from 5.4 to 50% in the higher level, which indicates that the students analyze SSIs from different dimensions: scientific, ethical, cultural, social, economic and environmental. This percentage also shows that in the post-test students are more informed about the production of energy in the department of Boyacá and include the importance of the generation of energy through alternative sources. In the following affirmation, made by student E53, their opinion on privatization is expressed, once the intervention had been realized:

E53: "I do not agree; first because it is a company that belongs to us and, second, because all companies may have economic or productivity problems at some point, what is obvious is that they want to sell it to a single organization and they are not taking into account what the people who have worked at the company say."

Table V. Comparison between the pre-test and post-test in competence IV

	High	Medium	Low	Insufficient
Pre-test	27.0	51.7	14.2	7.1
Post-test	89.2	10.7	7.1	-
p value	0.0*	9.9·e-8*	0.001*	0.97

In competence IV: *Assessment and making of ethical judgments.* A 58.7% rise stands out, which accounts for the importance of making ethical judgments regarding SSIs, attending to their contribution and the satisfaction of human needs. In this competence, it is highlighted that the students make statements related to the implementation of electric power in the country and make a professional assessment with respect to the topic. As can be seen in the opinions of E2 and E19 as an answer to the question: *Do you agree with the privatization of EBSA? Why?*

E2 in the post-test: "In my opinion, the country should implement better practices to obtain electricity. Colombia has a large variety of terrains that are suitable for the implementation of alternative energies, apart from hydroelectric and thermoelectric,

such as wind and solar, what is important is to think about the future of the new generations."

E19 in the post-test: "Electric power companies should not only think about the economic aspect, but also come up with strategies for the use of resources, seeking the least possible harm, so as to maintain balance in the environment."

They also take their own stance as future teachers of the natural sciences who promote citizen formation and the development of values for the democratic participation in topics of science and technology, as students E43 and E53 point out in their interventions.

E43. "It is necessary to seek for renewable sources of energy, such as solar or wind, and in the departments that are closer to the sea, tidal energy can be used. In that way, pollutants would be partially stopped. For example, projects with students can be implemented where the advantages and disadvantages of diverse types of processes of electricity generation can be studied, and at the same time teach concepts such as energy, types of energy, etc."

E53: "At present, the country has many companies, but as a future teacher of the natural sciences I think that the impact that they have on the environment should be looked at, these can be mitigated through cooling towers and other alternatives."

Table VI. Comparison between the pre-test and post-test in competence V

	High	Medium	Low	Insufficient
Pre-test	12.5	28.5	12.5	46.4
Post-test	85.7	7.1	1	-
p value	0.0*	0.001*	0.16	2.6·e-12*

In competence V: *Conclusions and decision-making* there are very significant values in the high and medium levels. This indicates that the students make statements regarding decisions at a personal, work and family level. Also, it is evidenced that the percentage of students in the low and insufficient levels drops. By way of example, the intervention of student E14 is presented:

Intervention by student E14 in the post-test: "More than decisions, we need to train ourselves in ethical values because if we know that these methods are not the most

adequate, we need to look for others that do not harm the environment so seriously and, on the other hand, we must give our opinion about energy with the aim of preventing the problems that are taking place. For my part, it is important to have more knowledge on the topic so as to be able to reflect upon energy saving in educational institutions."

Intervention by student E14 in the pre-test: "We have to be ready because prices will rise due to privatization."

The previous affirmations prioritize the need to promote spaces for reflection regarding the topic of energy saving. This contributes to making possible spaces of critical consciousness and social responsibility, in this case from their position as teachers of the natural sciences.

Implications of SSIs in the pre-test and post-test

In order to show the changes brought about by the intervention in each competence, not only at a percentile level, but also analyzing the changes that each of the students have experienced, we will use tables of contingency. Below, the analysis of the implications of SSIs in the pre-test and post-test is presented.

For the pertinent analysis, 4x4 squared tables are used, the data of which comes from paired samples, given that, in the research the same students took part in the pre-test as well as in the post-test. At the same time, the categories used in rows and columns correspond to high, medium, low and insufficient levels.

Table VII. Comparison between the pre-test and post-test in competence I through contingency tables

		COMPETENCE I (PRE)				
		High	Medium	Low	Insufficient	Total
POST	High	23	21	5	2	51
	Medium	3	1	0	0	4
	Low	1	0	0	0	1
	Insufficient	0	0	0	0	0
	Total	27	22	5	2	56

The table indicates the change the students have gone through. In the diagonal, there appear those who have not changed, on the top right corner, those who have

improved and in the bottom left corner, those who have worsened. In the pre-test, 21 were in the Medium level, 5 in Low and 2 in Insufficient, and they rose to the High level in the post-test. It is observed that 3 students dropped, in the pre-test they were in the High level and, in the post-test, they went down to Medium level. At the same time, it is observed that 1 student worsened, going from High to Low level. There are 24 students who remain the same, 23 that had a High level in the pre-test and 1 that was registered in the Medium level.

In this sense, the data delivered by the R program allows us to obtain the value of the statistical c2 = 18.16 and a value $p<0.00$which indicate the contribution of the SSI to the understanding of science as a social activity.

Table VIII. Comparison between the pre-test and post-test in competence II through contingency tables

		COMPETENCE II (PRE)				
		High	Medium	Low	Insufficient	Total
POST	High	4	22	20	4	50
	Medium	0	2	3	0	5
	Low	0	0	1	0	1
	Insufficient	0	0	0	0	0
	Total	4	24	24	4	56

In competence II, the positive effect of the intervention is observed in 46 students. This allows us to infer that the students question the information presented to them, which means to assess the impacts of the thermal and hydroelectric plants as producers of energy. Among the most common answers, the ones that stand out are those referring to environmental impact, followed by climate change, greenhouse effect, the effect of the plants on the biodiversity of marine ecosystems and the displacement of people from their places of origin.

In competence III, the rise of 27 students to the High category is observed. In the post-test, no students are reported in the Insufficient level. Out of the 8 registered in this level in the pre-test, 3 scaled to the High level and 5 to the Medium level. It can be seen that 8 students of the Medium level, 4 of Low and 1 from High, remained the same. Therefore, in this competence, 23% of the students were not affected by the didactic intervention. In contrast, 2 students who were in the High level worsened in the post-test.

Table IX. Comparison between the pre-test and post-test in competence III through contingency tables

		COMPETENCE III (PRE)				
		High	Medium	Low	Insufficient	Total
POST	High	1	13	11	3	28
	Medium	1	8	9	5	23
	Low	1	0	4	0	5
	Insufficient	0	0	0	0	0
	Total	3	21	24	8	56

The statistical test allows us to obtain a value of c2 = 31.09 and a value $p < 0.00$ which is significant so as to assess how the participants include various dimensions, such as the scientific, ethical, cultural, social, economic and environmental in the analysis of the SSI referring to the privatization of electricity. Likewise, they relate aspects such as the production of combustion reactions of coal, oil or gas that heat a liquid with a lot of pressure and Faraday's Law, etc.

In competence IV, the chi-squared test of marginal homogeneity shows a statistical value of the contrast of symmetry of c2 = 33.68 and the value $p < 0.00$. For this matter, the result indicates that the SSIs allow for the linking of essential instruments for citizen participation, such as the production of clean energies, the implementation of energy saving strategies, the use of energy for social wellbeing and the generation of actions at a curricular level for the adequate use of energy.

Table X. Comparison between the pre-test and post-test in competence IV through contingency tables

		COMPETENCE IV (PRE)				
		High	Medium	Low	Insufficient	Total
POST	High	13	29	5	3	50
	Medium	2	0	3	1	6
	Low	0	0	0	0	0
	Insufficient	0	0	0	0	0
	Total	15	29	8	4	56

In this competence, there are positive changes in the post-test. The data indicates that 37 students have gone up to High level whereas 3 students, who were in the Low level, went up to Medium. Those students who were in the Insufficient level have

improved and ascended to the scales High and Medium. In the post-test, there are no students in the lowest categories.

Finally, in competence V, the statistical test calculated in R allows us to obtain the statistical value c2 = 40.41 and a value $p < 0.00$. The answers of the post-test deal with general aspects that highlight the participation and information regarding problems affecting the public sector, the impact of companies. In addition, the participants show ideas of their own, from their training as science teachers, where they highlight the importance of promoting critical positions and prioritize the need to originate spaces for reflection with regard to the topic of energy saving.

Table XI. Comparison between the pre-test and post-test in competence V through contingency tables

		COMPETENCE V (PRE)				
		High	Medium	Low	Insufficient	Total
POST	High	6	13	6	23	48
	Medium	1	2	1	0	4
	Low	0	0	0	0	0
	Insufficient	0	1	0	3	4
	Total	7	16	7	26	56

Discussion

The data obtained in the two tests is surprising in various aspects. One is related to the significant increase by 73.2% in the High level, of competence V: Conclusions and decision-making with $p < 0.00$. This means that more coherent arguments with personal or familiar decisions are collected, apart from linking their profession as future science teachers to positions regarding the SSI. This coincides with what was found by Day and Bryce (2006), the SSI may have a significant role in scientific and citizen training. Therefore, it is evidenced that SSIs contribute to constructing new statements and conclusions, adequately supported, which lead to making well-supported decisions.

Another aspect is related to the highest degree of difficulty that competence III continues to have for the students. To study the socio-scientific issue in a comprehensive way, in its complexity, in a way that scientific, technical, ethical, cultural, social, economic and environmental dimensions are involved. It is important

to highlight an increase from 5.4% in the highest level to 50%. This may be due to the fact that it requires a greater level of comprehension in multiple topics and establishing relations among them.

The above reflects that the students relate, to some extent, the concepts of chemistry with the description of energy generation. However, many only transcribe the image presented in the test without any interpretation whatsoever. The data indicates that in the post-test the participants are more informed about the production of energy in their region. They also include the importance of the generation of alternative and renewable sources in coherence with other studies (Driver, Newton and Osborne, 2000; Sadler, 2004; Windschitl, Thompson and Braaten, 2008), which indicates how the use of SSIs in a science class offers opportunities for the development of a citizenry capable of applying scientific concepts and promoting ethical consciousness. Other aspects that stand out in the post-test are related to better-supported answers with regard to the production of electricity in the country.

The statistical analysis carried out with the chi-squared test of marginal homogeneity of Stuart and Maxwell indicates a favourable effect in all the competences with values $p < 0.05$ and reflects a reduction in the number of students who do not respond to questions in the post-test. Nevertheless, the data indicates a greater improvement in competence II: To learn to question information; competence V: Conclusions and decision-making, and competence IV: Assessment and Making of ethical judgment, considering that these registered a greater number of students in the Low and Insufficient levels in the pre-test.

The above shows that the use of SSIs in the classroom facilitates the development of critical competences. Therefore, promoting pedagogical and didactic processes from within the classroom from the SSI approach can strengthen the processes of the development of critical thinking. Thus, the results presented show an inclusion of the social aspect in the study of the scientific concepts in consistency with Albe (2008); Rundgren, and Yao (2014), according to whom the teaching of science must have a meaning in social interactive processes where the human being learns and interacts with the reality of others. This suggests that the influence of the context constitutes a possibility to reflect upon social, economic and political topics.

In the same way, it also allows for the promotion of communication processes in the classroom, and as Van Zee and Minstrel (1997); Seyhan (2015) point out, spaces for

the students to express their thoughts, comments and questions must be fostered. This gives the students the responsibility of thinking and contributing in order to articulate ideas, beliefs and concepts. In the same way, the data obtained agrees with the studies of Albe (2008), and Dawson and Venville (2010), which indicate how the construction of arguments in a collaborative way may facilitate better-supported arguments and opinions. In this study, the activities about the consumption of coffee and the use of glyphosate were dealt with in groups.

Finally, the data shows that the SSIs allow for approaching real problems from social, environmental, and scientific aspects that promote the formation of well-supported opinions. These situations, different from what is regularly used in science classes, allow for the localization of the issue in an environment or context that makes the learning of scientific concepts more meaningful. This is important as a contribution to the autonomy that teachers may have when designing the curricula. It also favours the possibility of creating collective spaces of study and curricular planning which go beyond the accumulative, homogeneous, linear and the technical rationality approaches.

Conclusions and implications

The data indicated significant contributions of the SSIs to the critical competences in this research, regarding the topic of the privatization of electricity. However, it reflects that the students relate, to some extent, the concepts of chemistry with the description of the process of energy generation, the use of the terms pressure, Faraday Law, and the generation of HNO3, H2SO4 acids; but this requires a level of understanding and clarity, of the scientific lexicon as well as of the daily use of the language, in order to establish pertinent analogies that demand the attention of the teachers in the teaching of science. In competences I and V, it was evidenced that the students understand the problem of privatization as an object of reflection of the sciences, and this contributes to generating reflections and making personal and collective decisions.

It is necessary to promote processes of critical thinking in science classes and there should be more emphasis on developing this in each one of the disciplines that involve aspects referring to the questioning of information, multidimensionality, the making of solid argumentations, the ethical dimension, the establishment of

conclusions, and the decision-making process from the SSIs approach. All this, with the aim of improving aspects regarding the observation of the problem in a comprehensive way, articulating different dimensions and designing didactic proposals that allow us to share outlooks and experiences about the sciences from different points of view.

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