Cypriot Journal of Educational Sciences

Volume 15, Issue 2, (2020) 220-231

www.cjes.eu

A study on the effectiveness of a teaching based on socio-scientific issues in the training of pre-service teachers

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Suggested Citation:

Cayci, B. (2020). A study on the effectiveness of a teaching based on socio-scientific issues in the training of pre-service teachers. *Cypriot Journal of Educational Science. 15*(2), 220–231. https://doi.org/10.18844/cjes.v15i2.4604

Received September 2, 2019; revised February 5, 2020; accepted April 2, 2020.
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Abstract

In this study, two different learning approaches (the Toulmin model of argumentation and whole class discussion technique) to the training of primary school teachers in Turkey were tested over socio-scientific issues. On the one hand, we identified how prospective teachers experienced a change of mind on these issues before and after the training, and on the other hand, we analysed the changes on their argumentation and attitudes. In this research model, the distribution of participants is in 53 experimental groups and 52 control groups, and the group equivalence transactions are done. The study was used three different measurement tools, such as attitudes towards socio-scientific Issues Scale, argumentation test and the Teacher Efficacy Scale. The study included teaching processes based on socio-scientific issues (SSI) for 5 weeks each. Furthermore, the indecisiveness participants displayed in socio-scientific issues completely disappeared in the teaching group following the Toulmin model, and each member of this group made a definite decision on the issues covered.

Keywords: Socio-scientific issues, teacher candidates, argumentation model.

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1. Introduction

In today's world, the scientific developments have a rapid effect on the social order and individuals' lives. As newly emerging needs bring along new problems, individuals are required to devise solutions that account for scientific perceptions, social implications and individual concerns. This is a proficiency that needs to be kept up to date in terms of knowledge, skills and emotional characteristics. On the other hand, the technological advances constitute the most important outcome of the rapid developments in science. These advances are reflected on the society and create different perceptions, views and social debates on certain matters to give rise to socio-scientific issues (SSI). SSI are controversial areas based on science, involving scientific and social issues (Sadler, 2004; Topcu, Sadler & Yilmaz-Tuzun, 2010). In other words, they inherently bring up dilemmas that are open to debate (Sadler & Zeidler, 2005; Kolsto, 2001).

An issue must meet at least two criteria to qualify as socio-scientific: it must involve science and have social significance (Eastwood et al. 2012; Topcu, Mugaloglu & Guven, 2014). According to the criteria listed by Atabey and Topcu (2017), Ratcliffe and Grace (2003) and Topcu (2017), it must be based on science, rely on scientific knowledge and evidence, require to make a choice and develop an opinion, have a frequent presence in daily life through media, be on a local, national or global dimension and require a filter of values, ethics or morality.

As seen, SSI ought to display many characteristics. The most notable of them is the requirement of a local, national or global scale. Under this characteristic, noted by Ekborg, Ottander, Silfver and Simon (2013), issues such as global warming, nuclear energy or genetic engineering are global (Sadler & Donnelly, 2006; Sadler & Zeidler, 2005; Zohar & Nemet, 2002), mass poultry extermination to combat avian flu or seal hunting is local (Lee & Grace, 2012; Zeidler & Nichols, 2009) and the planned nuclear power plant in the region of Akkuyu, Mersin, Turkey, or the 'green road' project to connect the Turkish Provinces of the Black Sea region is national (Evren-Yapicioglu & Kaptan, 2017; Kirbag-Zengin, Kececi, Kirilmazkaya & Sener, 2011).

Another remarkable characteristic is that these issues always include a dilemma, they are up for debate and they do not have a single correct solution and are not free of personal judgements (Zeidler & Nichols, 2009). Therefore, the decision on an SSI also requires individual moral judgement and an ethical filter. This process, called informal reasoning, is described by Sadler (2004) as an individual's capability to analytically evaluate a complex situation without resorting to simple solutions. Sadler and Zeidler (2005), on the other hand, argued that informal reasoning has rational, emotional and intuitive patterns. Topcu (2017) provided the following example for these patterns: when making a decision on nuclear power plants, an individual may consider the energy production needed (rational), empathise with the people living in the area where the plant will be constructed (emotional) or respond negatively remembering the nuclear accidents in the past (intuitive).

Such the societal effects of SSI only show the importance of the responsibility to develop scientific literacy as the primary purpose of science education. The concept of scientific literacy includes cognitive, affective and skill-related elements, as well as applying and using knowledge in daily life. Therefore, scientific literacy can be defined as the ability to develop scientific solutions to problems within the boundaries of social responsibility. A two-way process, whereby SSI use improves scientific literacy, which in turn finds effective solutions to SSI, makes up the focus of some recent research. For example, the studies such as Sadler (2011) and Zeidler (2001) indicated that science education objectives can be attained effectively and permanently through SSI.

The view that what counts in today's science education is 'explanation and argumentation, rather than discovery and experimentation' was adopted also in Turkey, and SSI made its way to the Turkish primary school science curriculum in 2013 (MoNE (Turkish Ministry of National Education), 2013). According to Dawson and Venville (2010), the presence of the SSI in a curriculum is indicative of a will to improve the scientific literacy. Therefore, it is possible to claim that the primary school science curricula in Turkey serve the purpose of raising scientifically literate students. It should be noted, however, that class teachers aiming to improve scientific literacy among their students must themselves be scientifically literate.

This brings us to the important question that 'what approaches to teaching would be most effective for SSI in science education'? Eastwood, Schlegel and Kristin (2011) answered this question with a classroom environment based on student-centred learning and promoting informal reasoning. Main approaches in such a classroom setting would be the argumentation-based instruction (Atabey & Topcu, 2017; Dawson & Venville, 2010; Sadler & Donnelly, 2006; Zohar & Nemet, 2002), problem scenarios (Sadler, 2003), dilemma cards (Oliveira, Akerson & Oldfield, 2012), web-based inquiry (Slotta, 2004; Walker & Zeidler, 2007) and group or whole-class discussions (Dawson & Venville, 2010; Lewis, 2000; Lewis & Leach, 2006).

The argument used in the test group as one of these approaches is the product based on the discourse emerging out of a discussion to support a claim, and the argumentation refers to the process whereby it emerges (Kuhn & Udell, 2003). Toulmin (2003) defined an argument as the justification of decisions, beliefs, attitudes and values, whereas argumentation was the process through which these arguments were developed. The Toulmin argumentation model is a student-centred process, whereby a claim based on knowledge is either supported or rejected through activities. This model has six components: claim, data, warrant, backing, rebuttal and qualifier.

The discussion method used in the control group of the research allows teacher–student and student–student interaction and encourages students to think and share ideas. One of the techniques of this method is the large group (class) discussion. According to Surgenor (2010), this technique takes place with the participation of the whole class and is teacher centred. Students are divided into two groups based on the opinions that they support and engage in an exchange of ideas under the supervision of the teacher. Teacher leads the discussion and keeps it going until it the assurance that all aspects of the subject are understood.

In light of the above explanations, the aim of this study was to find the most effective way to use SSI to improve the scientific literacy by the way of comparing the teacher-oriented large group (class) discussion and the student-oriented Toulmin argumentation model. Thus, the prospective class teachers supposed to raise scientifically literate students in Turkey throughout their careers shed light on how SSI would be used best in their undergraduate education to improve their own scientific literacy.

1.1. Purpose of the study

In consideration of the above, the general aim of the research was defined as 'to study how the SSI teaching designed according to Toulmin's argumentation process affected primary school teacher candidates in terms of their success in argumentation and attitudes'. The study also sought answers to the following subproblems:

1. How are the SSI perspectives of prospective teachers distributed in the test and control groups before and after the experimental procedure?
2. According to the post-test scores of the prospective teachers, is there any significant difference between the test and control groups in terms of success in argumentation and attitudes to SSI?

2. Method

According to the aims defined, the experimental model was chosen as the quantitative research method to be employed, and the study was conducted according to the 'pretest–posttest control group' design. A symbolic view of the study characteristics is shown in Table 1.

Table 1. Symbolic view of the experimental study design

Groups	Pre-tests	Applications	Post-tests
Experimental group	AT ATSIS TES	SSI teaching based on Toulmin argumentation	AT ATSIS
Control group	AT ATSIS TES	SSI teaching based on a large group (whole class) discussion	AT ATSIS

AT: Argumentation test, ATSIS: Attitudes towards SSI scale, TES: Teacher efficacy scale.

2.1. Study groups

The study was conducted with the undergraduate program of pre-service primary school teachers in a public university in Turkey, during the spring semester of the 2017–2018 academic year. The class teacher training program included two branches in the 3rd year. We chose to conduct the study with 3rd-year students, because of the program, because science courses in Turkey started in the third grade.

To determine whether the branches to be assigned as test and control groups were equivalent, the data obtained from the AT, attitudes towards SSI scale (ATSIS) and teacher efficacy scale (TES) applied to both before the experimental procedure were analysed using the independent *t*-test statistical process, and the results are shown in Table 2.

Table 2. Independent *t*-test results of the experimental and control groups with regard to AT, ATSIS and TES scores before the experimental procedure

Scales	Groups	*N*	*M*	SD	*T*	df	*p*
AT	Experimental control	53 52	38.08 41.56	11.26 9.74	−1.694	103	0.093 $p > 0.05$
ATSIS	Experimental control	53 52	116.94 114.50	10.89 13.40	1.026	103	0.307 $p > 0.05$
TES	Experimental control	53 52	55.47 56.88	5.23 5.32	−1.372	103	0.173 $p > 0.05$

Table 2 shows no significant difference between the AT pre-test scores ($t(103) = -1.694$, $p > 0.05$), ATSIS pre-test scores ($t(103) = 1.026$, $p > 0.05$) and TES pretest scores ($t(103) = -1.372$, $p > 0.05$) of test and control groups. In light of these results, it can be argued that the test and control groups are similar in terms of their success in argumentation, SSI attitudes and teaching efficacy.

Based on these results, the randomised method was preferred for assigning the branches as test and control groups, and branch A consisting of 53 participants was assigned as the experimental group and branch B with 52 was assigned to the control group. The trainings with the defined approaches were performed for the same length of time (a total of 5 weeks) in both groups under the guidance of the researcher.

2.2. Data collection tools

TES was used only as a pre-test tool to determine the general qualifications of the participants in the teaching groups. These qualifications include preparing for the course, instructing, managing student performances and motivating the student effort. In this sense, TES was considered as an important variable for the equivalence of the study groups as it was a requirement to establish the equivalence of the participants in terms of their self-stated qualifications. TES, developed by Gibson and Dembo (1984), consists of 21 items categorised into a 5-point Likert type scale. The original scale consists of 11 items related to external factors on the efficacy of teachers and 10 related to personal factors. In the Turkish adaptation by Diken (2004), followed by validation and reliability studies, the number of items was reduced to 16. Of these, seven are related to internal and nine to external factors. The reliability coefficient is 0.71. The conclusion reached was that TES could be used in Turkey to determine the overall efficacy of teachers.

The first of the measurement tools used as a pre- and post-test in the study was the ATSIS. This scale, consisting of a total of 30 items in a 5-point Likert type, was developed by Topcu (2010), and the validity and reliability studies were conducted with the data obtained from 216 prospective teachers. A total correlation value of each item in the scale was found higher than 0.50 with exploratory factor analysis, a result which was then backed with confirmatory factor analysis.

The second tool used as pre- and post-test is the AT, measuring the argumentation skills and the competence in using them. This test, developed by Sampson and Clark (2006), was adapted to Turkish by Kaya, Cetin and Erduran (2014), who later conducted relevant validity and reliability studies. AT was finalised on evaluations in terms of language, meaning, content and suitability for measurement by the respective specialists. It was applied to 36 senior students in the English teaching department and satisfied the linguistic equivalence criterion (r = 0.79). Moreover, AT was applied to 252 prospective science teachers in its final form and returned a reliability coefficient of 0.67. It consists of three questions to define scientific arguments and three to formulate the objections developed against a scientific argument.

Furthermore, permissions to use whole measuring tools were obtained from the original researchers via e-mail.

2.3. Procedure

The SSI used in each study week are as follows in the same order: (1) genetically modified organisms (GMOs) and their effects on human health, (2) flu vaccine and decisions on its use, (3) nuclear power plants and their effects on living and non-living environment, (4) possible consequences of indiscriminate use of medicines and (5) waste and recycling.

The participants in the experiment group were given the SSI of each week a few days in advance and had enough time to make their research. After that, they prepared written reports following the Toulmin model of argumentation and explained the information that they found, the meanings and understandings they formed and the decisions they made. On the basis of these arguments, the participants were grouped according to the thesis–antithesis system and provided as many participants as possible to present their own reports. In a democratic and respectful application setting that the researcher provided, they explained their arguments on a voluntary basis, and with courage and confidence, they interacted with one another during the Q&A and discussion. During the interaction, they formulated their objections (counterarguments) to claims opposite to their own and challenging statements. Thus, while defending their own claims, they also made statements to refute and disprove counterclaims.

Once the presentations and discussions in the test group were over, the researcher wrapped up the issue with reference to both the scientific literature and related current practices in Turkey, on a global scale, answered the questions of the class and finalised that week's course. The researchers avoided leading or pressuring the participants in their decision-making processes.

Participants in the control group also received that week's SSI, a few days in advance, but they did not prepare written reports of the meanings, understandings and decisions that they formed. They shared them in a large group (class) discussion instead without previously shaped written claims and arguments. Again, opinions were explained in an environment of democratic participation, freedom of expression and respect with the leadership of the researcher and Q&A session followed. Finally, the process ended with the researcher wrapping up, summarising and answering the questions from the class.

The application processes in the test and control groups lasted for 3–3.5 hours on average each week and with breaks of 15 minutes.

2.4. Analysis of the data

The researcher took the observational notes during all the group teaching processes and entered the final decisions of the participants in the observation form. Based on the data in the observation form, the frequency and percentage values required for the first subproblem were calculated.

The data collected with post-test measurement tools were recorded using the package software SPSS 24, and they underwent the statistical analyses. The normality of the data obtained for the second subproblem was tested with Kolmogorov–Smirnov, and it was concluded that the variables had a normal distribution with 95% confidence. The Levene's test was used to verify the variance homogeneity, and based on the results obtained, a decision was made to use the parametric test (independent samples *t*-test).

3. Results

3.1. Findings for the first subproblem

Table 3 shows the analysis results of the data for the first subproblem presented in the study.

Table 3. Frequency and percentage results of the experimental and control groups' views on SSI before and after the experimental procedure

		Experimental group				Control group			
		Before Experimental Procedure		After Experimental Procedure		Before Experimental Procedure		After Experimental Procedure	
		n	%	*n*	%	*n*	%	*n*	%
Consumption of GMO products	Positive	5	9.43	9	16.98	6	11.32	11	20.76
	Negative	5	9.43	44	83.02	5	9.43	15	28.30
	Neutral	43	81.14	0	0	42	79.25	27	50.94
Flu vaccination	Positive	7	13.21	32	60.38	12	22.65	7	13.21
	Negative	1	1.88	21	39.62	8	15.09	18	33.96
	Neutral	45	84.91	0	0	33	62.26	28	52.83
Nuclear power plants	Positive	1	1.88	31	58.49	2	3.78	13	24.53
	Negative	3	5.66	22	41.51	5	9.43	10	18.87
	Neutral	49	92.46	0	0	46	86.79	30	56.60
Indiscriminate use of medicines	Positive	8	15.09	0	0	7	13.21	2	3.77
	Negative	40	75.48	53	100	41	77.36	43	81.14
	Neutral	5	9.43	0	0	5	9.43	8	15.09
Recycling of waste	Positive	14	26.42	53	100	19	35.85	32	60.38
	Negative	24	45.28	0	0	18	33.96	12	22.64
	Neutral	15	28.30	0	0	16	30.19	9	16.98

On a review of Table 3, it is possible to summarise the important result findings from the test and control groups as follows:

The percentage of participants, who categorically rejected the use of GMOs and food products obtained from them, was 83.02% in the test group and 28.3% in the control group. On the other hand, in the test group where the SSI was covered according to the Toulmin model of argumentation, the entire section of 81.14%, who previously abstained about the GMO consumption before the experimental procedure, was distributed to either of the other groups afterwards. Before the experimental procedure, the same distribution was 79.25% in the control group covering SSI based on the large group (class) discussion, and it persisted after the experimental procedure even if decreased to 50.94%.

The same situation was observed in the issues of flu vaccination, nuclear power plants, indiscriminate use of medicines and waste recycling. These results suggest that the inclusion of the argumentation process in the management, investigation, interpretation and final decisions of SSI eliminates abstainers by leading them to resolute decisions on the said issue. However, in the large group (class) discussion process, the neutral opinion persists even if it decreases to a certain extent following the debates.

Finally, the processes leading to positive or negative judgements on the selected SSI vary. In other words, while some issues are for hot debates with the positive or negative views showing persistence, in some of them, the majority of participants end up with similar judgements and make the similar decisions. For instance, the opinions on constructing nuclear power plants for national energy production may vary, whereas almost all participants share the same view on the use of medicines without the control and prescription by a physician. In summary, the number of abstainers on more controversial SSI is high in the test group before the experimental procedure, but these are distributed to the other two groups after it. On the other hand, on issues with a relatively low level of controversy, the abstainers (neutrals) before the experimental procedure are generally gathered around one single opinion afterwards. However, this situation is true for the test group only, and it was not observed in the control group.

3.2. Findings for the second subproblem

Table 4 shows the analysis results of the data for the second subproblem presented in the study.

Table 4. Independent *t*-test results of the experimental and control groups with regard to AT and ATSIS scores after the experimental procedure

Scales	Groups	*N*	*M*	SD	*t*	df	*p*
AT	Experimentalc	53	52.51	12.52	4.915	103	0.000
	ontrol	52	40.62	12.27			$p < 0.05$
ATSIS	Experimentalc	53	122.66	9.45	3.279	103	0.001
	ontrol	52	116.29	10.44			$p < 0.05$

As shown in Table 4, a significant difference in favor of the test group was found in the AT post-test scores [$t(103) = 4.915$, $p < 0.05$] and ATSIS post-test scores [$t(103) = 3.279$, $p < 0.05$] of the test and control groups. Considering the arithmetic averages, it can be argued that the participants in the test group are significantly higher in general in terms of their success in argumentation and the attitudes towards SSI.

Based on these findings, it is possible to state that using the Toulmin model of argumentation in covering SSI has a positive or improving effect both on developing argumentation skills and positive attitudes towards SSI. However, it was also found that large group (class) discussions based on an exchange of statements and opinions did not have a positive or improving effect on the argumentation success or SSI attitudes of the participants.

4. Discussion and conclusion

There is a plethora of literature on these topics (SSI) used in the study including nuclear power plants (Kirbag-Zengin et al., 2011; Ozden, 2015), global warming (Atabey & Topcu, 2017; Klosterman & Sadler, 2010; Sadler, Chambers & Zeidler, 2004; Topcu, 2008; Topcu et al. 2010), human genetics and genetic engineering (Dawson & Venville, 2010; Lewis & Leach, 2006; Sadler & Donnelly, 2006; Sadler & Zeidler, 2005; Zohar & Nemet, 2002), waste and recycling (Kortland, 1996), H5N1 virus and mass extermination of chickens (Lee & Grace, 2012) and genetically modified foods (Walker & Zeidler, 2007).

At the end of the teaching process, the abstainer position of the participants in the test group due to inadequate knowledge and awareness was completely dissolved, whereas the same persisted in the control group at an above-average degree. For example, on the issue of whether or not to be vaccinated against the flu, about 45 test group participants (84.91%) with a neutral (abstaining) position before the experimental procedure developed a resolute position either way after the procedure. In the control group, however, when the number of neutral participants was 33 (62.26%) before the experimental procedure, it dropped only to 28 (52.83%) afterwards. Based on the observations on the teaching processes managed personally by the researcher and on participant statements, this situation shows that the participants using the Toulmin model of argumentation were able to make a resolute decision on SSI relying on their scientific knowledge, values, attitudes, beliefs, ethics and morality. The reason was that the large group (class) discussions in the test group mostly took place in accordance with a narration-based setup with a uniform, teacher-centred approach.

Furthermore, the percentages of participants making a positive (for) or negative (against) decision and act accordingly varied based on the character of the particular SSI. For example, in the test group, after the experimental procedure, some participants (60.38%) supported the flu vaccination, whereas some (39.62%) were against it; however, on the issue of waste recycling, all participants (100%) stated the positive views. This indicates that the participants using the Toulmin model of argumentation in scientific debate made their decisions on different SSIs according to different informal reasoning processes. However, this situation was experienced in the test group only and was not observed in the control group due to the difficulty of following definite systematics for the high number of abstainers.

These two results obtained as the findings of the first subproblem of the research suggest that the use of the Toulmin model of argumentation initiated a change in the curiosity and interest levels about SSI and guided the participants to make better-informed decisions through discussions supported by scientific research and also to engage their emotional responses. As stated by Sadler and Zeidler (2005), SSI involves more than one viewpoints and solution proposals, resulting in informal investigations in addition to formal, as well as emotional and intuitive responses in addition to rational. In this case, it can be suggested that the use of the Toulmin model of argumentation influenced the informal reasoning capabilities of the participants and led them to make informed decisions.

The analysis of the second subproblem revealed that the SSI discussion in accordance with the Toulmin model of argumentation improved both the argumentation success of the participants [$t(103) = 4.915$, $p < 0.05$] and their attitudes towards SSI [$t(103) = 3.279$, $p < 0.05$].

Dawson and Venville (2010), Klosterman and Sadler (2010), Kolsto (2001), Ogunniyi and Hewson (2008), Sadler (2006) and other studies suggested that the use of argumentation skills in teaching processes based on SSI improved the quality of the arguments and success levels. What these studies have in common is the recognition that the decision-making on issues with dilemmas, alternative solutions or perspectives as SSI does not only involve the evidence-based information but informal reasoning and argumentation processes such as ethics, attitudes and values, as well. In their study conducted with 10th graders using the argumentation process, Venville and Dawson (2010) suggested an increase in argument quality and rate of informal reasoning, pointing out the correlation between the argumentation process and informal reasoning. On the other hand, in their study with prospective teachers, Topcu et al. (2010) found a strong relationship between SSI and using informal reasoning, emphasising the interaction between the content of the SSI and informal reasoning.

Both the findings of this research and the conclusions of the abovementioned studies suggest that there is a strong interaction between the elements of the Toulmin model of argumentation and SSI components (the dilemma characteristic and the rational, emotional and intuitive components of informal reasoning. This is supported by Zohar and Nemet (2002), who conducted a study with the students in the 7th–9th and 9th–12th grades, as well the Atabey and Topcu (2017) study with the 7th graders. Both found that education based on SSI was one of the best ways to develop argumentation skills in students).

However, this rapport between the Toulmin model of argumentation and SSI was not attained with the large group (whole-class) discussion technique. This is an indication that, in the large group discussion, participant statements are not supported by scientific evidence, no informal inferences can be made in the decision-making process and debate based on rhetoric alone does not yield an effective solution. As a matter of fact, Dawson and Venville (2010) showed that the argument quality was higher in the areas involving argumentation training, whereas in the process based on whole-class discussion, this success depended on active involvement by the teacher.

Topcu (2010) pointed out to the studies investigating how the issues of science, technology and society shape the student attitudes towards science, as well as those examining how SSI influence students' interests and motivation. Among these, Yager, Lim and Yager (2006) and Lee and Erdogan (2007) indicated a positive change in student attitudes in the group using the issues of science, technology and society. Moreover, Zeidler, Sadler, Applebaum and Callahan (2009) found that student interest in lessons and learning improved after the SSI teaching. There are also studies on various SSI examining participant attitudes towards certain issues (Kilinc, Boyes & Stanisstreet, 2013; Ozdemir, 2014; Qin & Brown, 2007). For example, Sturgis, Cooper and Fife-Schaw (2005) found a positive correlation between participants' knowledge level and attitudes about these issues. However, it is also seen that there is more room for studies on student attitudes following the SSI discussions with the Toulmin model of argumentation. In this study, on the other hand, the attitudes of the participants towards SSI were also examined after the SSI discussion based on the Toulmin model of argumentation, and they were found to improve.

Based on all study findings combined, it is concluded that in controversial topics such as SSI, prospective class teachers should be encouraged to engage students not only in scientific discussion but also debates based on informal reasoning, as well. After all, these subject matters and their application constitute an important step for class teachers towards scientific literacy. By this process, they can acquire an important competence to help them raise scientifically literate students throughout their careers.

In the light of these results and explanations:

1. Interesting topics such as SSI should be added to primary school teacher candidates' science learning processes.
2. Discussion areas should be added to the science learning processes of primary school teacher candidates. These discussions should require using the power of interpretation accompanied by scientific evidence.
3. Competencies in the first two items should be taken into consideration in the selection and appointment of teachers.
4. In-service trainings should be provided for primary school teachers on behalf of effective science learning and teaching.
5. In these in-service training, SSI must be added to the science curriculum. Besides, the studies that combine cognitive processes (such as interpretation and criticism) and some items (such as research and scientific evidence) should be conducted.
6. Access should be facilitated in sources containing interesting research and interesting information in science. Platforms that can access this kind online and printed resources should be increased.
7. Finally, activities and materials related to such interesting topics in science should be prepared and made available.

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