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Analysis of Argumentation Structure in Students' Writing on Socio-scientific issues (SSI): Focusing on the Unit of Climate Change in High School Earth Science I

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Abstract: In this study, we analyzed the development of high school students' argumentation through their writings on socio-scientific Issues (SSI) related to the Climate Change Unit in the Earth Science I curriculum. Pre- and post-writing assignments on the two main causes of global warming were analyzed and compared. In addition, an in-depth interview of the focus group was conducted with 7 students who showed a distinct change in the level of argumentation. According to the results, 16 of 52 students remained at the same argumentation level in pre- and post-writing assignments, and students remaining at Level 2 among five levels had difficulty in understanding the Toulmin's argument pattern (TAP) structure. Using the TAP structure, 29 of 52 students demonstrated increased argumentation levels in the post-writing assignments. The conclusions include that writing lessons on SSI using the TAP in Earth science classes can improve the level of high school students' argumentative writing, and that the level of students' argumentation can develop with the elaboration of their level of falsification. Also, it is suggested that the science curriculum should increase students' science writing competencies by specifying science writing as one of the goals.

Keywords: argument, argumentative writing, SSI, TAP (Toulmin's argument pattern)

Introduction

The rapid advancement of science has splendidly developed our civilization and is envisioning a hopeful new era. Unlike this social trend, however, science as education does not respond to this trend. According to OECD (2003), students cannot solve complex problems arising in a rapidly changing society with school education that emphasizes only traditional knowledge. Accordingly, science educators are trying to achieve the goal of science education by focusing on 'cultivation of scientific literacy' that can recognize and solve the relationship between science, technology, and society by developing scientific thinking skills and creative problem solving skills (MEST, 2011).

According to previous studies (Fowler, Zeidler, and Sadler, 2009; Zeidler, Sadler, Simmons, and Howes, 2005; Wee et al., 2014), science educators have recently begun to pay attention to socio-scientific Issues (SSI) education, which is meaningful for students to use science and technology correctly, and to properly raise them as global citizens with the right judgment and character for these debates. The current goal of science education, focusing on SSI, is well suited to fostering 'scientific literacy' (Zeidler et al., 2005; Lee et al., 2014).

This scientific literacy requires information-based decision-making skills when dealing with socially important scientific issues (Sadler and Zeidler, 2005). It is necessary to identify factors such as the cause and effect of issues, and the pros and cons of solutions, select appropriate scientific knowledge, and judge and think (Jang and Chung, 2009). In order to develop these decision-making abilities, therefore, the

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current science and curriculum emphasize science writing and discussion (Park, 2005). Students should have the opportunity to learn not only scientific knowledge, but also science learning, the role of language, scientific culture, and social interaction in the process of constructing scientific knowledge through argumentation activities (Osborne et al., 2004), where effective learning can occur by identifying relationships between concepts and selecting information during the argumentation process (Wee et al., 2014).

The process of students' scientific thinking and logical reasoning is revealed through argumentation (Abell, Anderson, and Chezem, 2000; Kim et al., 2015). When considering the characteristics of SSI that can develop decision-making ability based on these argumentation activities (Albe, 2008; Dawson and Venville, 2010; Hogan, 2002; Lee et al., 2014), argumentation writing activities using SSI is a very suitable activity to develop students' scientific knowledge (Wee et al., 2014).

Toulmin's argument pattern (TAP) is frequently used to analyze argumentation activities (Ko, Choi, and Lee, 2015; Oh and Kim, 2009). This is a way to determine the structure or intention of an argument by logically analyzing it, and it can be applied to general situations (Nussbuam et al., 2011). Erduran et al. (2004) and Osborne et al. (2004) quantified the argumentation activity based on the frequency of the argument element, and compared and evaluated the quality of argumentation based on the change in frequency. They determined the level of falsification in the students' argumentation discourse, and then divided the qualitative level of argument into five stages by examining the frequency corresponding to each level.

Duschl (2003) suggested Evidence-Explanation Continuum based on the NRC's statement that students participate in data acquisition activities, determine evidence from the data, and derive explanations based on the evidence (NRC, 2000). In addition, by synthesizing the evidence-based reasoning process, which is an essential feature of scientific inquiry, and Toulmin's argumentation framework, Furtak et al. (2010) and Brown et al. (2010) also proposed Evidence Based Reasoning in Science Classroom Discourse (EBR-Discourse).

Kuhn (1986, 1993) also emphasized the importance of science as argumentation and exploration for the development of students' scientific thinking while students "practice justifying theories, presenting alternative theories, presenting counterargument, and providing rebuttals through argumentation with peers and teachers" (Park, 2005: 5). Park (2005) studied how students' scientific arguments were developed through science classes in middle schools in the US using the TAP.

Previous domestic studies, however, mainly focused on the development of the level of debate among college students, including pre-service teachers, or focused on the analysis of the structure of arguments revealed in science textbooks (Kim and Kim, 2015), and studies on the development of science argument structures for high school students are hard to find (Kim et al., 2015).

In this context, this study aims to analyze the level of argumentation of high school students with the result of argumentative writing using TAP. Other than exploring the cognitive execution aspects of students' conversational and collaborative argumentative discourse, or focusing on the degree to which teachers contribute to students' argumentative reasoning, this study focuses on analyzing the characteristics of students' argumentation structure revealed in their data interpretation and writing about SSI topics using the analysis framework of Osborne et al. (2004). Based on this, implications for high school students' argumentative writing lessons will be drawn. This study has limitations in that it is difficult to grasp the process of constructing argumentation or the degree of contribution of teachers to the development of students' argumentation reasoning (Park, 2005). The specific research questions for this research are as follows:

First, in the high school earth science class where the demonstrative writing class about SSI takes place, what are the developmental levels and characteristics of the demonstrative level and falsification in student writing? In addition, what are the developmental patterns and characteristics of falsification in students

who participated in the argumentative writing class about SSI?

Second, what factors influence the change of students' position and the development of the argumentation structure in the argumentative writing about SSI?

Methods

This study was conducted for students taking the second year of Earth Science I, a high school in Jeollabuk-do. A total of 57 students from two classes participated in this study. Prior to the implementation of the study, through the seminars with three science education experts of the Earth Science major, the contents of the Earth Science I textbooks and teachers' reference books were analyzed, and the Earth Science topics were selected to clearly understand the facts and structures of the argumentation. Among the issues related to climate change included in the 2009 Revised High School Earth Sciences I textbook, human-made or natural factors of global warming' was selected as an argumentative writing topic on SSI, and reading materials are developed. The topic for argumentative writing used in this study is as follows:

> It is said that there are two causes of global warming. One is a human-made factor, and the other is a natural factor. Read the presented reading materials carefully, and then 1) choose one of the two causes, and 2) write an argumentative writing that can persuade another person who has the opposite position.

Based on the achievement standards of the 2009 revised curriculum and the Earth Science I textbook, three experts in science education developed Toulmin's argumentation structure (TAP) activity sheet for 5 consecutive lessons. The process of conducting SSI writing classes and collecting data is as follows: First of all, in order to grasp the basic level of argumentation of the students, in the first week's writing, Toulmin's argumentation structure (TAP) was explained, and only topics and reading materials were presented before writing practice. After that, students practiced writing with each component of the TAP using different subjects for each class during five-week classes. That is, by adding elements of argumentation at each class, the result of each lesson were expressed in argumentative writing according to the TAP, so that the students became familiar with the TAP. After finishing the 5th class, argumentative writing data were collected on the same subject as the pre-writing, and students were asked to write persuasive writing with the elements consisting of the TAP in mind.

In order to explore the developmental pattern of students' argumentation level, pre- and post-writing were compared and analyzed. In this study, the level of argument was analyzed based on the presence or absence of falsification using the Osborne argumentation level analysis framework that emphasized falsification among the elements of Toulmin's argument (Osborne et al., 2004). The analysis framework is shown in Table 1. The students' writing results were analyzed by three experts who majored in science education using the analysis framework (Osborne et al., 2004) to determine the level of argumentation of each student.

In addition, semi-structured focus group interviews

Table 1. Writing analysis framework using TAP (Osborne et al., 2004)

Level	Explanation	Remarks
Level 1	Claim (C)+Data (D)+None Rebuttal (NR)	
Level 2	Claim (C)+Data (D)+Warrant (W)+None Rebuttal (NR)	
Level 3	Claim (C)+Data (D)+Warrant (W)+Backing (B)+Week Rebuttal (WR)	showing a falsification with a repetition of words, illogical things, etc.
Level 4	Claim (C)+Data (D)+Warrant (W)+Backing (B)+Clear Rebuttal (CR), ※ Including an unnecessary claim or opposite argument.	showing a falsification with unnecessary claims, a wrong falsification, other claim, or etc.
Level 5	Claim (C)+Data (D)+Warrant (W)+Backing (B)+Clear Rebuttal (CR)	showing an explicit falsification

were conducted with seven students who showed a marked change in the five-week argumentative writing. Seven students include four students whose argumentation level increased by 2 levels pre- and post-writings and three students who reached Level 5 in the post-writing. The in-depth interview questions include students' reactions and perceptions of SSI, factors that influenced the development of students' argumentation structure, students' perceptions of TAP, how to use TAP, and ways to improve it. The results of the focus group interview were recorded and transcribed, and three science education experts, including researchers, jointly analyzed and coded the data, and derived the main topics. In the light of previous studies, the main topics derived by the researchers were reviewed and discussed.

Results and Discussion

1. Change of argumentation level: Developmental pattern of falsification

The developmental patterns and characteristics of rebuttal (R) showed by 52 students who participated in the study were examined. Figure 1 shows the change in students' level of argumentation. Based on the developmental pattern of falsification (R), the research results are presented in three types: Staying at the same argumentation level, Decrease of argumentation level, and Increase of argumentation level in pre- and post-writings. Also, based on the results of in-depth interviews with the focus group, the factors that contributed to the development of the student's argumentation level were also discussed.

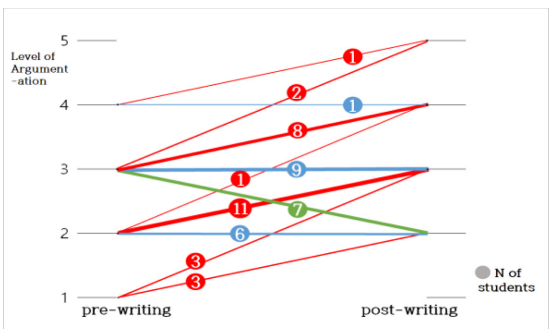

Fig. 1. Developmental pattern of falsification.

1) Maintain the level of argumentation

16 out of 52 students maintained the same argumentation level in pre- and post-writings. The features of these students are as follows:

Frist, 6 students stayed at Level 2 of the argumentation level in the pre- and post-writings (Level 2→2). Four of them, who took the position of human-made factors consistently, failed to present the rebuttal (R) factor in both pre- and post-writing and repeatedly presented their claim (C) based on the objective fact provided in the reading material without providing any recognition or rebuttal elements of the opposing claim. One student, who took the position of natural factors consistently, failed to present any rebuttal (R) elements repeated his claim (C) based on the objective facts provided in the reading material, but failed to provide refusal (R) or perception for human-made factors. Another student, who changed his position from natural to human-made, also failed to provide any rebuttal elements. These students had difficulty in understanding the TAP structure.

Second, 9 students stayed at Level 3 of the argumentation level in the pre- and post-writings (Level 3→3). Six of them, who took the same position of either human-made or natural factors consistently, refuted the other's position after presenting their own rebuttal (R) data. 3 students, who changed their positions from natural to human-made, presented weak rebuttals (WR) in both pre- and post-writing. For example, a student maintained human-made factors consistently provided a weak rebuttal in his pre-

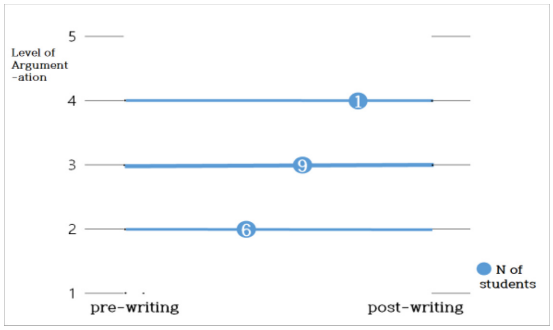

Fig. 2. Number of students maintained the level of argumentation.

writing stating that "The US president Trump refused to join the Paris Treaty on the grounds that it was a natural cause, but the carbon increase caused by a natural cause is a very small amount of carbon emitted by humans for 200 years." He remained at Level 3 in the post-writing providing a weak rebuttal that "human-made factors caused by logging and increased use of fossil fuels were overwhelming compared to the amount of carbon that nature removes through respiration of jungle bushes." In addition, one student stayed at Level 4 of the argumentation level in the pre- and post-writings (Level 4→4) without any development of elaborated rebuttal or backing.

2) Decrease the level of argumentation

7 out of 52 students showed decrease in their argumentation level with Level 3 in the pre-writing and Level 2 in the post-writing (Level 3→2). The features of these students are as follows:

First, 5 students, who took the same position of human-made factors consistently, presented rebuttal (R) factors in pre-writing, but failed to present any rebuttal (R) factor in post-writing. For example, a student maintained human-made factors consistently provided a weak rebuttal in the pre-writing by presenting "natural factors are very small damage over a very long period of time and the nature itself reduces carbon dioxide emissions through self-purification, but the potion of human-made factors by human behaviors due to excessive use of electricity and defense is much larger." In post-writing, he presented only arguments and evidences for human-made factors caused by population growth and industrial development without any rebuttal.

This is not a problem of instructional treatment using an argumentation structure, but students with low academic achievement may not be able to organize their thoughts according to the TAP in a state of lack of understanding of the argumentation elements. Or, these students may be the result of not accepting the other's claim and maintaining a firm position that their thoughts are unconditionally correct.

Second, 2 students, who changed their positions from natural to human-made, presented the rebuttal (R) factor beforehand but failed to present the rebuttal (R) factor afterwards. In this case, students who insisted that global warming was caused by natural factors in advance, and then changed their position to human-made factors afterwards due to classes or other experiences. They seemed to have been persuaded by the warrant of the human-made factor (W) and changed their position without providing a valid rebuttal (R) of the natural factor.

After all, in the process of changing positions, the vulnerabilities of one's position could not be logically presented, and these students were persuaded by another person's warrant (W) without presenting a valid rebuttal (R) of their own position. In addition, even if they adhered to their own position without changing their stance, students with low academic achievements were not able to organize their thoughts with the lack of understanding of the argumentation elements of TAP after vaguely writing about the claims they would like to make. In fact, some students stated that the writing process in accordance with the TAP was more difficult than expected.

3) Increase the level of argumentation

29 out of 52 students showed increased argumentation level in the post-writing. The features of these students are as follows:

First, 6 students, who took the same position of either human-made or natural factors consistently, showed Level 1 in the pre-writing and Level 2 or

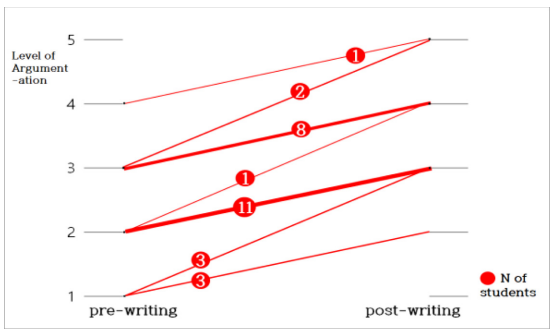

Fig. 3. Number of students increased the level of argumentation.

Level 3 in the post-writing. These students simply presented their position without any own claim based on the fact provided in the reading material in the pre-writing, and reinforced their claim (C) through warrant (W) and backing (B). 3 students further disproved the other's position by taking a rebuttal (R) element to the opposite position.

Second, 11 students showed Level 2 in the pre-writing and Level 3 in the post-writing by adding backing (B) and week rebuttal (WR) to their claims. ten of these students, who took the same position of human-made factors consistently, reinforced their position with backing (B) and week rebuttal (WR) in their post-wring. One student, who changed his positions from natural to human-made, presented backing (B) and week rebuttal (WR) for their changed positions. This student suggested natural factors in the pre-writing with warrant arguing that "a change in temperature occurred in accordance with the change in solar activity from the 1400s to the present, and thus global warming was resulted from the natural factor." However, in the post-writing, changing his position to human-made factors, he presented a weak rebuttal arguing that "there may be the influence of natural factors, but it is difficult to trace the exact causal relationship in the case of natural factors."

Third, 8 students presented weak rebuttals (WR) of the opponent's position in pre-writing, and a clear rebuttal (CR) in post-writing based on scientific evidence by inserting an unnecessary claim (C) into the rebuttal (R), which caused them to stay at level 4 (Level 3→4). 6 out of 8 students, who maintained the same position consistently, reinforced their claim with a clear rebuttal (CR) in post-writing. 2 out of 8 students (Level 3→4), who changed their position from natural to human-made factors, presented clear evidence of rebuttal (CR) with changing positions. These students suggested that it was due to human-made factors through the warrant (W) and backing (B), and at the same time presented a clear rebuttal (CR) regarding the problem of the natural factors, which are their previous position. In other words, they were consolidating their changed position by utilizing the favorable function of a rebuttal (R).

Fourth, one student showed Level 2 in the pre-writing and Level 4 in the post-writing while maintaining human-made position consistently. He failed to present any rebuttal (R) elements in the pre-writing but provided clear rebuttals (CR) to human-made factors based on scientific evidence in post-writing (Level 2→4).

Lastly, there were 3 students (Level 3→5, Level 4→5) who showed the perfect argumentation structure corresponding to Level 5. These 3 students stayed at Level 3 or Level 4 with using a weak refusal (WR) or a clear refutation (CR) with unnecessary claims (C) in pre-writing, but used only necessary phrases for clear refusal (CR) in the post-writing. Unlike pre-writing, where they did writing without any framework, these students seemed to refine their writing in the process of writing using the structure of TAP. In other words, it suggests that the writing experience of sharpening a strong warrant (W) or backing (B) about one's position using activity sheets was effective for improving students' argumentation skills.

2. Factors influencing students' argumentation structure development

According to the in-depth interview with 7 students, the factors that influenced the development of students' argumentation structure are as follows:

First, students insisted that their argumentation structure developed as they "write systematically based on confidence in self-assertion using the system or framework of TAP" while refuting the grounds of self-assertion as well as the other's claim. In particular, students said that they first followed the format of the TAP, and later the content of their writing became richer as a result of grasping the meaning of the TAP components, which resulted in the development of the argumentation structure.

> Student C: I usually get lost when I write, but I learn the process one by one in class, so I slowly learn the grounds, rebuttal, and some acceptance of the opponent's claims. As I became aware of the process of writing, I seem to have written with ease.

Student D: If you try to write without a foundation at first, it is difficult to learn the argument structure, look for evidence or things related to self-assertion, and continue to look at the other side's opinions. I think that I can give and persuade the other person, so I keep looking for it and I try to write more. In the pre-writing, I just wrote it because I didn't know how to write it, but since the teacher showed me how to write evidence 1, evidence 2, results, etc. in order, so I seem to have written more elaborately afterwards than before.

Student E: When I first wrote it, I wrote it without knowing any framework, and then as I took the framework of the argument structure and disproved the other's claim through the class, I think my argument became stronger and I could write better.

Student F: Even though I knew the frame in the beginning, I first put words into each element. With continuous writing, it seemed to improve the writing as the contents in it became richer.

Second, students explained that they wrote only in the form of self-assertion in pre-writing, but they improved their writing as they try to provide a basis of disproval evidence for the opposite argument.

Student A: At first, I just wrote my claim first, and I wrote it in a form that persuaded me to speak the grounds of my argument without context. And then I learned the structure of the argument and wrote not only self-assertion but also the grounds for the argument against me. In the process of judging whether the grounds are right or wrong, I learned a lot of things that can persuade others more easily and quickly.

Third, repeated encounters with TAP helped develop students' argumentation structure. Students rated the practice and repetitive experience as helpful.

Student B: In simple terms, the more experience you have, the more likely it has been the cause of development. Repeatedly, it seems that the writing is improved with repeated corrections to the writing.

Student E: In the pre-writing, I wrote everything in my head without thinking. However, it seems that the argument structure improved because the teacher later had me practice writing using the frame with grounds, claim, etc.

Student F: After writing, I learned the writing frame, and practiced a lot through the class, so I seemed to improve my essay skills naturally.

Finally, depending on the students' understanding of the presented data, the developmental pattern of the student's argument structure is varied. Students explained that the developmental patterns of the students' argumentation structure will vary depending on the student's background knowledge required to understand the presented data. The focus group students explained that most of the students consistently maintained human-made position since the scientific explanation related to natural factors was difficult for them to understand. According to the result, 24 out of 29 students who showed increase of the argumentation level consistently maintained human-made position, which may be resulted from the fact that the scientific explanation related to natural factors was difficult for them to understand. 2 students, who changed their position from natural to human-made, explained that they changed their positions because the data or evidence supporting human-made factors were easy to understand while the reasons or explanations for natural factors were somewhat difficult for students to understand.

Student C: The data or evidence supporting the human-made factor was easy to understand, and it was easy to find the writing components. However, the evidence or explanation for natural factors was difficult to understand.

Student E: The reason for maintaining the human-made factor was that data related to natural factors were also insufficient, and the evidence for the natural factor does not make sense.

Student F: The friends who changed their positions probably took the natural factor to try to deny the human-made factor somehow, and then looked into it and found out that the natural factor was a bit far-fetched, and they changed their position.

After all, in writing about SSI about the causes of global warming, students can acquire scientific knowledge through classes and then reinforce their positions by adding backing (B) or rebuttal (R) data in post-writing

by utilizing the TAP structure.

Conclusion

This study examined the developmental process of the argument structure in students' writing on SSI in the High School Earth Science I Climate Change Unit. Pre- and post-writing of 52 students were compared and analyzed on the two main causes of global warming. According to the results, 16 out of 52 students stayed at the same argumentation level in pre- and post-writings, and students stayed at Level 2 had difficulty with understanding the TAP structure. Seven out of 52 students showed decrease in their argumentation level with Level 3 in the pre-writing and Level 2 in the post-writing, and most of them could not provide a valid rebuttal for their changed positions. 29 out of 52 students showed increased argumentation level in the post-writing by using the TAP structure. Based on the research results, the conclusions and suggestions of this research are as follows:

First, the level of high school students' argumentation writing can be improved if teachers provide an argumentative writing class about SSI. The process of development of students' level of argumentation showed a slightly different pattern according to the change of position, but the students who maintained their positions consistently between pre- and post-writing strengthen the elements of the argumentation structure and enriched the content of their writing with objective evidence as the experience of writing accumulates. In addition, by adding backing (B) or rebuttal (R) data, which were not used in pre-writing, students further strengthened their views and reached an improved level of argumentation.

Second, the level of rebuttal (R) is elaborated through writing classes on SSI topics that utilize TAP in high school earth science classes. In other words, as the level of argumentation improves, students not only claim their own opinions, but also develop their own claims (C) through rebuttal (R) with the opponent's position or claims in mind. By specifying science writing, as one of the goals of all science and curriculum including earth science, it is necessary to increase students' science writing competency.

Third, according to in-depth interviews with students, students changed their positions based on the amount of objective data and evidence and the degree of understanding of the data they encountered. The factors that influenced the development of students' argument structure were the system of TAP, repeated practice of TAP, and rebuttal writing. When designing and implementing writing lessons on SSI topics that utilize TAP, it is necessary to consider the composition of the materials provided to students, the TAP system, and repetitive strategies, etc. to help promote the development of students' argumentation structure.

Based on these conclusions, suggestions for follow-up studies are as follows:

First, it is necessary to develop more cases that can be used for earth science and argumentative writing, and to provide systematic teaching and learning materials and models so that students can easily understand the structure of argumentation. Through this, it is expected that in the long term, students will be able to develop their communication ability to logically communicate their scientific claims through improving their level of argumentation.

Second, it is necessary to derive implications for (earth) science education through follow-up studies exploring the cause and outcome of the development of demonstrative scientific writing levels, taking into account the student's background variables such as student achievement and personal abilities.

Third, it is necessary to develop teachers' related expertise in order to develop students' communication competency through argumentative writing. Teachers are responsible for teaching SSI writing, TAP, and scientific communication, and the learning outcomes are determined by teacher expertise and competence. Inclusion of argumentation writing and communication skills as explicit goals of science education, and creation of a professional development and support environment for (earth) science teachers should also be preceded.

The importance of argumentation activities is steadily

increasing as a way to cultivate the student's competency to communicate scientific arguments logically. Accordingly, many prior studies were conducted to evaluate the structure and effectiveness of the argumentation activities conducted in SSI classes. In order to, however, improve the level of argumentation of learners, it is necessary to prepare more practical methods such as effective teaching methods or strategies that can be applied in classroom teaching. This study confirmed that the level of students' argumentation was improved through argumentative writing classes that explicitly reveal and analyze the argument structure using TAP. Therefore, it is expected that the argumentative writing class using TAP can be an effective method to develop students' scientific communication skills.

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