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Argümantasyona Dayalı Öğretimin Fen Bilgisi Öğretmen Adaylarının Asit Yağmurları Konusundaki Anlayışlarına Etkisi

The Effect of Argumentation-Based Instruction on Pre-service Science Teachers' Understanding of Acid Rain

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Özet: Bu araştırmada argümantasyona dayalı öğretim yönteminin fen bilgisi öğretmen adaylarının asit yağmurları konusundaki anlayışlarına etkisinin belirlenmesi amaçlanmıştır. Araştırmada tek gruplu ön test son test desen kullanılmıştır. Araştırmanın örneklemini, Türkiye'nin batısında yer alan bir üniversitenin eğitim fakültesi Fen Bilgisi Öğretmenliği programında öğrenim gören 14 ikinci sınıf öğretmen adayı oluşturmuştur. Argümantasyona dayalı dersler "Kimyasal Atıklar ve Çevre Kirliliği" dersi kapsamında gerçekleştirilmiştir. Öğretim etkinlikleri araştırmacılar tarafından hazırlanmış olup öğretim 3 ders saatinde gerçekleştirilmiştir. Fen bilgisi öğretmen adaylarının asit yağmurlarıyla ilgili bilgilerini ölçmek ve öğretimin etkisini belirlemek için ilgili alanyazın araştırılarak (Asit yağmurları nasıl oluşur, Asit yağmurlarına sebep olan gazlar nelerdir, Asit yağmurlarının çevreye etkisi nasıldır, Asit yağmurlarının canlılar üzerine etkisi nasıldır, Asit yağmurlarını önlemek için neler yapılabilir) şeklinde beş tane açık uçlu soru hazırlanmıştır. Bu sorular fen bilgisi öğretmen adaylarına öğretim öncesi ve sonrasında uygulanmıştır. Araştırmadan elde edilen veriler betimsel analiz yöntemiyle incelenerek bulgular elde edilmiştir. Analizde kullanılan temalar, açık uçlu sorulara paralel olacak şekilde yapılandırılmış ve ortaya çıkan temalar öğretim öncesi ve öğretim sonrası karşılaştırılarak sunulmuştur. Araştırma sonucunda öğrencilerin asit yağmurlarının sebeplerine ve etkilerine yönelik kavramsal anlama düzeylerinde artış olduğu belirlenmiştir. Çalışma sonucunda, argümantasyona dayalı öğretim yönteminin öğrencilerin asit yağmurlarıyla ilgili kavramsal anlama düzeylerini olumlu biçimde etkilediği sonucuna ulaşılmıştır. Argümantasyon yöntemi fen bilgisi öğretmen adaylarının çevresel bir problem olan asit yağmurlarına çözüm geliştirmelerini sağlayıcı zengin bir tartışma ortamı sağlamıştır.

Anahtar Kelimeler: Asit yağmurları, argümantasyon, fen bilimleri

Abstract: This study aimed to determine the effect of argumentation-based teaching methods on pre-service science teachers' understanding of acid rain. A one-group pre-test and post-test design was used in the study. The sample of the study consisted of 14 2nd year pre-service science teachers studying in the science teaching department of the faculty of education of a university located in the west of Turkey. Argumentation-based lessons were carried out within the scope of the 'Chemical Wastes and Environmental Pollution' course. The researchers prepared the teaching activities was which were carried out in 3 lesson hours. In order to measure the knowledge of pre-service science teachers about acid rain and to determine the effect of teaching, five open-ended questions were prepared by searching the relevant literature (How acid rain occurs, What are the gases that cause acid rain, What is the effect of acid rain on the environment, What is the effect of acid rain on living things, What can be done to prevent acid rain). These questions were applied to pre-service science teachers before and after teaching. The data obtained from the research were analysed by descriptive analysis method, and findings were obtained. The themes used in the analysis were structured in parallel with the open-ended questions and the emerging themes were presented by comparing before and after the instruction. As a result of the study, it was determined that there was an increase in students' conceptual understanding of the causes and effects of acid rain. As a result of the study, it was concluded that the argumentation-based teaching method positively affected students' conceptual understanding levels of acid rain. The argumentation method provided a rich discussion environment for pre-service science teachers to develop solutions to acid rain, which is an environmental problem.

Key Words: Acid rain, argumentation, science

Introduction

Argumentation is a social process in which a student defends a scientific idea they believe in and attempts to refute opposing views using scientific data, and in which two or more people critique and structure arguments (Nussbaum, 2002; cited in Er & Kırındı, 2020). Toulmin (1958) defined argumentation as the process by which individuals structure their thoughts, justify them, and present evidence that supports or refutes these thoughts. In this process, claims are supported through justifications and evidence, and critical thinking and scientific debate skills are developed. According to Toulmin's Argument Model, a sound argumentation has three main components: claim (the thought being defended), justification (the fundamental reasons supporting this thought), and evidence (scientific data or observations confirming the justification). These components structure the argumentation process, supporting students in organising their ideas and reasoning. The argumentation-based teaching method is an approach that is gaining increasing importance in science education. It not only shows students that science is a social process but also enables them to achieve a deeper understanding of scientific concepts. Within the framework of science education, argumentation encourages students to view scientific information critically, while also allowing them to develop thought systems based on scientific evidence. Driver et al. (2000), emphasizing that argumentation is a social process, state that through the argumentation method, students will learn to think and debate like scientists, to distinguish non-scientific information, to interpret scientific information from different perspectives, and to construct arguments like scientists based on evidence. In this context, argumentation goes beyond teaching students ways to achieve scientific thinking; it encourages them to view science as an area of inquiry and debate.

Research on Students' Understanding of Acid Rain

The topic of acid rain is addressed in the current Science curriculum in Turkey, particularly in the "Matter and Industry" unit at the 8th grade level (Ministry of National Education, 2024). In this context, the aim is for students to understand that gases such as sulphur dioxide (SO_2) and nitrogen dioxide (NO_2), which are released into the atmosphere as a result of the combustion of fossil fuels, react with water vapour to form acid rain. Furthermore, the negative effects of acid rain on soil, water resources, vegetation, and historical structures are discussed, aiming to develop individual and societal responsibility awareness towards environmental issues. The topic is linked to disciplines such as chemistry (acid-base reactions), geography (industrial areas and wind directions) and environmental education (sustainable living), offering a multifaceted learning environment. During the teaching process, experiments, visual materials and discussion activities encourage active student participation, while values such as responsibility, sensitivity and cooperation are taught to reinforce environmental awareness.

There are numerous studies in the literature on acid rain involving different participant groups (secondary school students, high school students, teachers and pre-service teachers) (Ayvacı & Çoruhlu, 2009; Babuçcu, 2016; Boyes & Stanisstreet, 1998; Bulduk & Aydoğdu, 2022; Kıryak & Özdilek, 2019; Özcan & Demirel, 2019; Summers et al., 2001; Kahraman, 2020; Karakaya Cirit & Aydemir, 2021; Khalid, 2003; Wan et al., 2023). Research has revealed widespread misconceptions and knowledge gaps regarding the formation, sources, and effects of acid rain, particularly at the secondary school level (Ayvacı & Çoruhlu, 2009; Boyes & Stanisstreet, 1998; Karakaya Cirit & Aydemir, 2021). In this context, systematic conceptual errors have been found in interconnected topics such as global warming, the greenhouse effect, and acid rain (Özcan & Demirel, 2019), and students' knowledge levels have been found to be low.

These difficulties in the learning process once again highlight the critical importance of subject knowledge and conceptual understanding for teachers and teacher candidates. Indeed, a study conducted with pre-service science teachers found that deficiencies in fundamental chemistry topics such as acids, bases, and neutralisation also negatively affected their understanding of environmental issues such as acid rain (Babuçcu, 2016). Similarly, it has been determined that pre-service science teachers have misconceptions about the greenhouse effect (Kahraman, 2020), while chemistry teachers' explanations of the damage caused by acid rain, the ozone layer, and the greenhouse effect are inadequate (Wan et al., 2023). Furthermore, it has been revealed that participants struggle to limit the source of acid rain solely to human activities and to relate its formation mechanism to nitrogen and sulphur emissions (Babuçcu, 2016; Khalid, 2003). The effectiveness of various teaching methods has been investigated to address these problems experienced by participants. Research has shown that constructivist teaching methods such as TAGA (Kıryak & Özdilek, 2019) and the model-based inquiry approach in socio-scientific subject teaching can increase students' environmental awareness and conceptual understanding when applied with enriched activities (Bulduk & Aydoğdu, 2022). Teachers wishing to implement model-based activities in their classrooms are advised to prepare activities that encompass a variety of models in their model design work (Bulduk & Aydoğdu, 2022).

Recently, efforts have also been made to develop alternative materials. Balkız Kalkan and Çelikler (2024) developed scientific cartoons addressing environmental issues, including acid rain, within the framework of the "Human and Environmental Relations" theme for fifth-grade students. Çelikler and Aksan (2025) have also designed informative posters enriched with scientific cartoons to develop sustainable environmental literacy among secondary school students. Such visual and creative materials attract students' attention, concretise abstract environmental concepts, and ensure lasting learning.

All these findings clearly show that conceptual understanding and knowledge of acid rain must be developed at every level, from students to teacher candidates. Accordingly, Kahraman (2020) emphasised that, in order to increase pre-service science teachers' competence in this area, science education degree programmes should include more courses focused on environmental education and enriched with contemporary pedagogies.

Studies on the Effect of Argumentation Methods on Student Learning

The role and effectiveness of argumentation in science education is supported by research covering all levels of education from primary school to university. Studies have demonstrated the positive effects of this method on conceptual understanding, critical thinking, motivation, scientific literacy, and argumentation skills. One of the most prominent effects of argumentation is that it increases students' levels of conceptual understanding and reduces conceptual misconceptions. This has been demonstrated by Aygün et al. (2016) at primary school level on the topic of 'melting and dissolution' and by Kıryak and Özdilek (2019) at secondary school level on environmental topics such as 'acid rain'. At the secondary school level, Demirci-Celep (2015) on gases, Venville and Dawson (2010), and Zohar and Nemet (2002) on genetics found that the quality of students' arguments improved and their conceptual understanding strengthened in abstract and difficult subjects. Osborne and colleagues (2004) state that a similar environment ensures that science concepts are correctly linked within themselves. The argumentation process not only teaches students what they know but also teaches them how to use this knowledge. Kalemkuş and colleagues (2021) found in their study that argumentation significantly contributes to primary school pupils' critical thinking, prediction-observation-explanation and reasoning skills, while Er and Kırındı (2020) found that it significantly contributes to secondary school pupils' scientific process skills and academic achievement. Researchers conducting studies at secondary school and university levels emphasised that argumentation develops students' abilities to construct scientific evidence, share ideas, write scientifically (Antonio & Prudente, 2021), and make logical explanations (Eymur, 2019). Rivera et al. (2021) argued that argumentation increases student participation through critical thinking and should be used more frequently in science education. According to Çiğdemoğlu et al. (2017), the argumentation method contributes to scientific literacy. Through argumentation, students increase their interest in the subject and their participation in lessons. For example, it has been observed that secondary school students' interest in chemistry lessons has increased (Özelma & Güngör Seyhan, 2023) and that they can produce components such as claims, data, and justifications without getting bored in lessons supported by technological applications (Yıldırım & Sağlam, 2025). Furthermore, it has been emphasised that students' argumentation levels increase over time (Türk & Yıldırım, 2025) and that these skills can be significantly developed at secondary school level through problem-solving-focused lessons (Marthaliakirana, et al., 2022). All these findings demonstrate that the argumentation method is an effective teaching tool for science lessons. Researchers suggest that, in order to use this method more effectively, teachers should organise their lessons in a problem-solving-oriented manner (Marthaliakirana, et al., 2022) and organise their lessons by carefully combining technology tools, the argumentation process and content knowledge (Yıldırım Sağlam, 2025).

These studies, which employ argumentation methods, demonstrate that argumentation helps students better understand abstract and complex concepts, develops their critical thinking skills, and provides opportunities for students to recognise their existing misconceptions and correct these errors. Studies on environmental issues such as acid rain have revealed that students have insufficient knowledge about these issues. In lessons based on the argumentation method, it is possible for students to gain environmental awareness by understanding scientific issues affecting the environment, such as acid rain, and generating solutions through scientific and socio-scientifi&c discussions. Jiménez-Aleixandre and Erduran (2008) state that argumentation not only develops scientific thinking but also increases students' sense of social responsibility and awareness of environmental issues. This is of great importance in teaching environmental topics such as acid rain. With this method, students will not only learn how acid rain is formed but also become aware of their misconceptions. For these reasons, investigating the effect of the argumentation method on learning about acid rain will not only increase students' scientific understanding but also contribute to their development of environmental awareness, critical thinking, and social responsibility. This study aims to determine how argumentation-based teaching methods affect pre-service science teachers' understanding of acid rain and to identify their levels of argumentation on the subject. To this end, the following questions were addressed:

1. How does argument-based teaching affect pre-service science teachers understand of acid rain?
2. What are the argument levels of pre-service science teachers regarding acid rain, a socio-scientific issue?

Method

In this study, weak experimental methods were employed from among experimental methods, and within this framework, a single-group pre-test-post-test design was utilised. The most important feature of experimental methods is that they provide an opportunity to measure the cause-and-effect relationship between the variables to be observed (Köklü & Büyüköztürk, 2000). Based on the data obtained from a single experimental group, the difference between the pre-test and post-test scores is examined, and if a significant difference is found, it is accepted that this difference is due to the intervention (Baştürk, 2009).

Sample

The study involved 14 second-year science teacher candidates studying at an education faculty located in western Turkey. In the sample selection, convenient sampling was used from among non-random sampling methods. Büyüköztürk et al. (2015) define convenient sampling as selecting a sample that is suitable for the circumstances due to existing limitations such as time, money, and location. The names of the teacher candidates were not used to keep their identities confidential. The students were coded as PS1, PS2, PS3…. and PS14, and the groups were coded as G1 to G7.

Data Collection Process

The study process began with the pre-testing of the data collection instrument. Subsequently, the first author conducted argumentation-based teaching consisting of three lessons, each lasting 45 minutes. The argumentation-based teaching activities were prepared by the researchers. These lessons were conducted within the scope of the "Chemical Waste and Environmental Pollution" course. After the argumentation-based activities, the data collection tool applied at the beginning of the teaching was reapplied as a final test. The data collection and teaching process is shown in Figure 1.

In the argumentation activities, each student was given worksheets and asked to complete the activities individually first. Then, the students were asked to discuss in groups of 4-5, share their ideas and compare them. As a result of the discussions, the groups presented their arguments to the class through their chosen spokespersons. During the presentations, the teacher acted as a guide, encouraging students to formulate counterarguments in a questioning manner. At the end of the lesson, a general class discussion was held to evaluate the arguments presented and determine what constitutes a correct and strong argument.

In the first lesson, an activity aimed at introducing arguments to the students was carried out. In this activity, arguments and their components were explained through a dialogue between two students (Yıldırır, 2013). To enable students to experience the discussion and argument example first-hand, they were asked to discuss a current issue they were familiar with. The components of an argument were revisited using examples from the students' discussion. Students were presented with an argument example related to a science topic and asked to write an argument on any topic of their choice. Finally, the arguments written by the students were evaluated, and the characteristics of a good argument were emphasised. A concept cartoon was used in the second lesson. The concept cartoon presented two different claims about the effect of acid rain on lakes. Students were first asked to decide which claim was correct and then to support their claims with data and reasoning (Figure 2a). A sociological activity was prepared for the third lesson. In this lesson, students were given the worksheet shown in Figure 2b. Students were first asked to read the text on the worksheet. They were then asked to form pairs, discuss the topic, and present their arguments in a report. During their presentations, the groups discussed, defended their claims, tried to justify themselves, and attempted to persuade each other.

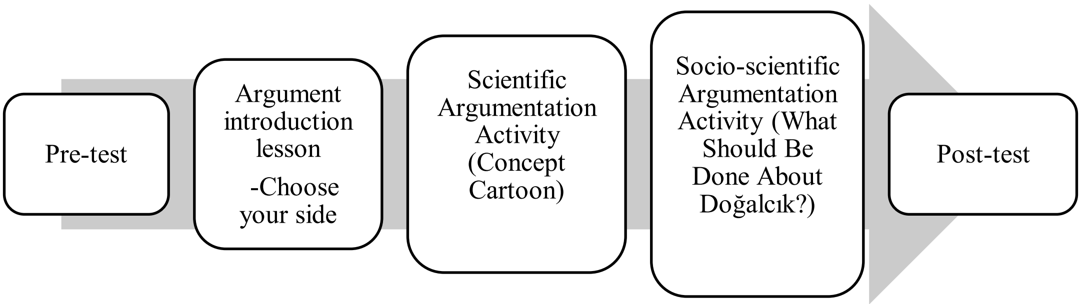
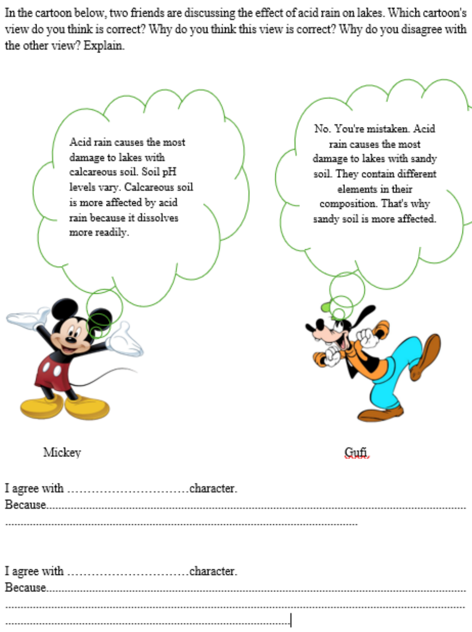


Figure 1. *Data Collection Process*



In the cartoon below, two friends are discussing the effect of acid rain on lakes. Which cartoon's view do you think is correct? Why do you think this view is correct? Why do you disagree with the other view? Explain.

I agree with ……………………………character.
Because……………………………………………………………………………………
……………………………………………………………………………

I agree with ……………………………character.
Because……………………………………………………………………………………
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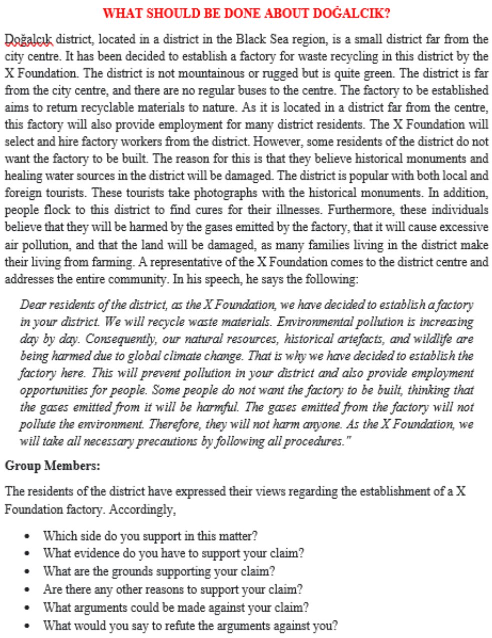
a) Scientific argumentation activity (Concept cartoon)



WHAT SHOULD BE DONE ABOUT DOĞALCIK?

Doğalcık district, located in a district in the Black Sea region, is a small district far from the city centre. It has been decided to establish a factory for waste recycling in this district by the X Foundation. The district is not mountainous or rugged but is quite green. The district is far from the city centre, and there are no regular buses to the centre. The factory to be established aims to return recyclable materials to nature. As it is located in a district far from the centre, this factory will also provide employment for many district residents. The X Foundation will select and hire factory workers from the district. However, some residents of the district do not want the factory to be built. The reason for this is that they believe historical monuments and healing water sources in the district will be damaged. The district is popular with both local and foreign tourists. These tourists take photographs with the historical monuments. In addition, people flock to this district to find cures for their illnesses. Furthermore, these individuals believe that they will be harmed by the gases emitted by the factory, that it will cause excessive air pollution, and that the land will be damaged, as many families living in the district make their living from farming. A representative of the X Foundation comes to the district centre and addresses the entire community. In his speech, he says the following:

Dear residents of the district, as the X Foundation, we have decided to establish a factory in your district. We will recycle waste materials. Environmental pollution is increasing day by day. Consequently, our natural resources, historical artefacts, and wildlife are being harmed due to global climate change. That is why we have decided to establish the factory here. This will prevent pollution in your district and also provide employment opportunities for people. Some people do not want the factory to be built, thinking that the gases emitted from it will be harmful. The gases emitted from the factory will not pollute the environment. Therefore, they will not harm anyone. As the X Foundation, we will take all necessary precautions by following all procedures."

Group Members:

The residents of the district have expressed their views regarding the establishment of a X Foundation factory. Accordingly,

- Which side do you support in this matter?
- What evidence do you have to support your claim?
- What are the grounds supporting your claim?
- Are there any other reasons to support your claim?
- What arguments could be made against your claim?
- What would you say to refute the arguments against you?

b) Socio-scientific argumentation activity

Figure 2. *Worksheets used in lessons*

Data Collection Tool

An open-ended questionnaire was used as a data collection tool to determine pre-service science teachers' understanding of acid rain and to learn about changes in their understanding as a result of teaching. Five open-ended questions were prepared by reviewing the relevant literature (Kıryak & Özdilek, 2019; Pabuçcu, 2016) to measure pre-service science teachers' knowledge about acid rain and to determine the effect of teaching. These questions were administered to pre-service science teachers before and after the teaching.

1. How are acid rains formed?
2. What gases cause acid rains?
3. What is the impact of acid rains on the environment?
4. What is the impact of acid rains on living organisms?
5. What can be done to prevent acid rains?

Data Analysis

Descriptive analysis was used in the analysis of open-ended questions. Descriptive analysis is an analytical approach that involves processing qualitative data, identifying findings, and interpreting the identified findings based on a predetermined theoretical framework (Yıldırım & Şimşek, 2016). Codes were created from the responses given by pre-service science teachers to the questions before and after the training, and sample statements for the codes were provided. The analysis of their arguments was conducted using the argumentation assessment rubric developed by Sadler and Fowler (2006). The assessment rubric consists of five levels of argumentation. The levels and explanations of the rubric are shown in Table 1.

Table 1. Argumentation Assessment Rubric (Sadler & Fowler, 2006)

Level	Explanation
0	No justification.
1	Justification with no grounds.
2	Justification with simple grounds.
3	Justification with elaborated grounds.
4	Justification with elaborated grounds and a counterposition.

To ensure the reliability of the data analysis, four randomly selected questionnaires containing open-ended questions were given to a chemistry educator who is an expert in the field. For argument analysis, the same teacher was asked to code the arguments of two groups. The reliability value was determined using the coder reliability formula proposed by Miles and Huberman (1994). The analysis reliability was calculated as 87% and 92% as a result of the calculation.

Results

The findings obtained in the study are presented in response to the research questions. The first section of the findings presents the analysis findings of the responses given by pre-service science teachers to open-ended questions before and after teaching, in response to the first research question. The second section presents the analysis findings of the arguments created by pre-service science teachers in the sociological argumentation activity, in response to the second research question. The findings of the analysis are tabulated, and these tables include the categories obtained according to the analyses and excerpts from the participants' views.

Results Related to the First Research Question

A questionnaire consisting of five open-ended questions was administered to pre-service science teachers before and after instruction. The first question in this open-ended questionnaire asked how acid rain is formed. The pre-service science teacher, who coded PS3, stated that she did not know about this issue before the instruction. The codes and sample statements created based on the answers given by other pre-service science teachers are presented in Table 2.

Table 2. Pre-service Science Teachers' Views on the Formation of Acid Rain (Pre-Instruction)

Category	Sample Statement	Participants	f	%
Gases	Sulphur dioxide, nitrogen dioxide and carbon dioxide gases released into the atmosphere undergo chemical transformations and are then absorbed by water droplets in clouds. These droplets subsequently fall as rain or snow (PS8).	PS1, PS5, PS7, PS8, PS9, PS10, PS11, PS13	8	61.53
Harmful gases	It refers to the harm caused to the environment and living beings by rain formed when harmful gases combine and mix into the atmosphere due to air pollution. (PS4).	PS2, PS4, PS12, PS14	4	30.77
Chemical rain	Also known as chemical rain.	PS6	1	7.7
Total			13	100

As shown in Table 2, three categories (gases, harmful gases, chemical rain) emerged from the pre-service science teachers' responses regarding the formation of acid rain prior to instruction. Eight pre-service science teachers stated that acid rain is formed as a result of the interaction of sulphur dioxide, nitrogen dioxide and carbon dioxide gases released into the atmosphere with water. Four pre-service science teachers stated that acid rain is formed by the mixing of harmful gases in the atmosphere, but did not mention what these gases are. The pre-service science teacher, who coded PS6, defined acid rain as simply a chemical rain without explaining how it is formed.

Table 3. Pre-service Science Teachers' Views on the Formation of Acid Rain (Post-Instruction)

Category	Sample Statement	Participants	f	%
Fossil fuels	The use of fossil fuels causes harmful gases such as SO_2(g) and NO_2(g), emitted from factory chimneys, to enter the water cycle and fall to the earth as acid rain (PS1).	PS1, PS2, PS3, PS5, PS6, PS7, PS8, PS9, PS10, PS11, PS12, PS13, PS14	13	92.86
pH	These are rains formed by the pH level falling below the normal value of 5.6 due to the gases released into the atmosphere.	PS4	1	7.14
Total			14	100

As shown in Table 3, two categories (fossil fuels, pH) emerged from the pre-service science teachers' responses regarding the formation of acid rain after the training. Thirteen pre-service science teachers' responses fell under the "fossil fuels" category, while one pre-service science teacher's response fell under the "pH" category. After the teaching session, the majority of pre-service science teachers believed that acid rain was caused by the use of fossil fuels and that the gases released as a result of burning these fuels caused acid rain. The pre-service science teacher with the code PS4 stated that acid rain would form as a result of a decrease in the pH value of the atmosphere due to the gases released into the atmosphere.

In the second question of the open-ended questionnaire for pre-service science teachers, they were asked what gases cause acid rain. The codes created based on the responses given by pre-service science teachers before and after the training are presented in Table 4.

Table 4. Pre-service Science Teachers' Views on Gases Causing Acid Rain

Gases	Pre-instruction			Post-instruction		
	Participant	f	%	Participant	f	%
SO_2(g), SO_3(g), SO(x)	PS1, PS2, PS3, PS5, PS6, PS7, PS8, PS9, PS10, PS11, PS12, PS13, PS14	13	34.21	PS1, PS2, PS3, PS4, PS5, PS6, PS7, PS8, PS10, PS11, PS13, PS14	12	46.15
NO_2(g)	PS1, PS2, PS5, PS7, PS8, PS9, PS10, PS12, PS13, PS14	10	26.32	PS1, PS2, PS5, PS7, PS8, PS9, PS10, PS11, PS12, PS13, PS14	11	42.31
CO_2(g)	PS2, PS3, PS5, PS6, PS7, PS8, PS9, PS11, PS13	9	23.68	PS2, PS3, PS6	3	11.54
Chlorofluorocarbon	PS1, PS3, PS7	3	7.89		-	-
H_2SO_4(g)	PS1	1	2.63		-	-
CO(g)	PS2	1	2.63		-	-
HNO_3(g)	PS1	1	2.63		-	-
Total		38	100		26	100

Table 4 shows that seven categories were formed from the responses given by the pre-service science teachers before the training, while three categories were formed after the training. It can be seen that the pre-service science teachers indicated that SO_2(g), SO_3(g), and SO(x) gases were the main causes of acid rain both before (f=13) and after (f=12) the training. In second place, both before (f=10) and after (f=11) the training, pre-service science teachers identified NO_2 gas as a cause of acid rain. CO_2(g) gas appeared in third place as a cause of acid rain both before (f=9) and after (f=3) the training. Some pre-service science teachers mentioned chlorofluorocarbon (f=3), H_2SO_4(g) (f=1), CO(g) (f=1) and HNO_3(g) (f=1) gases as the gases causing acid rain before the training.

The third question of the open-ended questionnaire asked pre-service science teachers about the effects of acid rain on the environment. The codes and sample statements created based on the responses given by pre-service science teachers before and after instruction are presented in Table 5.

Table 5. Pre-service Science Teachers' Views on the Environmental Impacts of Acid Rain

Category	Pre-instruction				Post-instruction			
	Sample Statement	Participant	f	%	Sample Statement	Participant	f	%
Impact on historical artefacts	It erodes many architectural structures and historical artefacts (PS9).	PS1, PS3, PS5, PS7, PS8, PS9, PS10, PS11, PS13	9	40.8	Our natural beauty and man-made sculptures and historical artefacts are eroded, causing their structures to deteriorate over time (PS1).	PS1, PS5, PS7, PS8, PS13	5	27.8
Effect on the soil	It damages the soil, reducing yield (PS5).	PS1, PS2, PS3, PS5, PS6, PS9, PS10, PS11	8	36.36	It disrupts the chemical composition of soil and water and reduces their productivity (PS3).	PS1, PS3, PS5, PS6, PS10, PS11	6	33.3

Impact on underground resources	It causes contamination of underground resources (PS6).	PS3, PS4, PS6	3	13.65	Acid rain seeps into the ground, contaminating groundwater and increasing the acidity level of our drinking water sources (PS10).	PS1, PS3, PS5, PS6, PS10, PS11	6	33.3
Toxic effect	It has a toxic effect on living organisms. (PS5).	PS5, PS12	2	9.1	It has a toxic effect on living organisms. It damages the respiratory and immune systems (PS5).	PS2, PS4, PS5, PS6, PS9, PS11, PS12	7	38.9
Total			22	100			18	100

Four categories were established based on the responses of pre-service science teachers regarding the effects of acid rain on the environment before and after training: "effect on historical artefacts", "effect on soil", "effect on underground resources" and "toxic effect". Table 5 shows that, prior to teaching, pre-service science teachers' responses indicated that acid rain had the greatest impact on historical artefacts (f=9) and the least impact on poisoning living organisms (f=2). Looking at the views after instruction, it is understood that the most common view was about the toxic effect of acid rain (f=7), followed by views related to its effect on soil (f=6) and underground resources (f=6). After instruction, fewer pre-service science teachers expressed views regarding the impact of acid rain on historical artefacts (f=5).

The fourth question of the open-ended questionnaire asked pre-service science teachers how acid rain affects living organisms. The pre-service science teacher, who coded PS5, stated that they had no opinion on this question before the instruction. The codes and sample statements created based on the answers given by the pre-service science teachers before and after the instruction are presented in Table 6.

Table 6. Pre-service Sceince Teachers' Views on the Effects of Acid Rain on Living Organisms

Category	Pre-instruction				Post-instruction			
	Sample Statement	Participant	f	%	Sample Statement	Participant	f	%
Effect on human health	Acid rain, which has a detrimental effect on living organisms, also poses a health risk (PS4).	PS1, PS3, PS4, PS7, PS8, PS9, PS10, PS11, PS13	9	69.23	Harmful substances from acid rain originating in the soil first pass into natural food products, and when we consume these products, they disrupt our body's metabolism (PS7).	PS7, PS11, PS13	3	21.43
Impact on biological diversity	It causes harm to fish, their death and a reduction in biological diversity (PS13).	PS3, PS7, PS13	3	23.08	-	-	-	-

Impact on the ecosystem	Due to the contamination of groundwater, it can be transferred through plants and cause harm.	PS6	1	7.69	When the chemical structure of the soil is disrupted, the main structures of plants may be disrupted and they may undergo physical changes.	PS3	1	7.14
Impact on living space	-	-	-	-	It has a negative impact on living organisms because it disrupts their habitats (PS14).	PS1, PS2, PS4, PS5, PS6, PS8, PS9, PS10	10	71.43
Total			13	100			14	100

Regarding the effects of acid rain on living organisms, pre-instruction responses from pre-service science teachers categorised their views into three groups: "effects on human health," "effects on biological diversity," and "effects on ecosystems." Post-instruction responses categorised their views into three groups: "effects on human health," "effects on ecosystems," and "effects on habitats." Table 6 shows that, prior to instruction, pre-service science teachers' responses indicated that they considered acid rain to pose the greatest risk to human health (f=9), followed by a reduction in biological diversity (f=3), and least of all, an impact on the ecosystem (f=1). Looking at the post-instruction views, it is understood that pre-service science teachers most thought that acid rain affected the living environment (f=10), followed by human health (f=3), and least thought that it affected the ecosystem (f=1). Pre-service science teachers did not express any views on the impact of acid rain on living spaces before the instruction, nor did they present any views on its impact on biological diversity after the instruction.

In the fifth question of the open-ended questionnaire for pre-service science teachers, they were asked what could be done to prevent acid rain. The pre-service science teachers with the code PS9 stated that they had no opinion on this question before the training. The codes and sample statements created based on the answers given by the pre-service science teachers before and after the instruction are provided in Table 7.

Table 7. Pre-service Science Teachers' Views on Preventing Acid Rain

Category	Pre-instruction				Post-instruction			
	Sample Statement	Participant	f	%	Sample Statement	Participant	f	%
Use of filters	Filters must be installed on factory chimneys (PS1).	PS1, PS3, PS5, PS6, PS7, PS8, PS10, PS14	8	47.1	We can install filters on the factory chimneys and thus reduce harmful gas emissions (PS14).	PS1, PS4, PS5, PS6, PS7, PS9, PS11, PS14	8	57.14
Awareness raising	The public must be made aware (PS3).	PS3, PS5, PS8, A12	4	23.5	-	-	-	-
Renewable energy sources	Renewable energy sources can be used (PS8).	PS4, PS8, PS13	3	17.7	Renewable energy sources should be used (PS13).	PS2, PS3, PS8, PS10, PS12, PS13	6	42.86
Transport	Public transport and bicycles should be used (PS2).	PS2, PS6	2	11.8	-	-	-	-
Total			17	100			14	100

Four categories were identified from the responses of pre-service science teachers regarding the prevention of acid rain: "use of filters", "awareness raising", "renewable energy sources" and "transport". According to the data in Table 7, similar opinions emerged regarding the "use of filters" category before and after instruction (f=8). Regarding the "awareness raising" category, only four pre-service science teachers stated that public awareness should be raised before instruction, while no opinions were expressed on this subject after instruction. Looking at the "renewable energy sources" category, three pre-service science teachers before instruction and six pre-service science teachers after instruction recommended the use of renewable energy sources. Regarding the "transportation" category, two pre-service science teachers, before instruction, stated that the use of public transport or bicycles in transportation could reduce acid rain; however, no opinions were expressed on this subject after instruction.

Results Related to the Second Research Question

In the third lesson, the pre-service science teachers held discussions on a socio-scientific topic. In this lesson, the students were given the worksheet shown in Figure 2b. The pre-service science teachers were first asked to read the text on the worksheet. They were then asked to form pairs, discuss the topic and present their arguments in a report. The arguments presented by the groups were analysed. The findings of these analyses are presented in Table 8 with sample arguments.

Table 8. Analysis of the Groups' Arguments

Level	Sample Argument	Group	f
0	-	-	-
1	-	-	-
2	We support the people. Historical monuments and healing springs in the district will be damaged. We believe the factory will harm the environment. Most families are farmers. The idea that the factory will not emit toxic gases and the job opportunities. We believe factories will emit toxic gases (G1).	G1 and G5	2
3	We support the residents of the district who oppose the establishment of the factory and believe that it should not be built. The district has historical monuments and medicinal water sources that attract tourists. A significant portion of the district's population earns their livelihood from farming. The gases and pollutants emitted by the factory could erode these historical monuments and contaminate water sources and agricultural land. This situation would negatively impact the region's fundamental economic activities, such as tourism and agriculture. The X Foundation's purpose should be to protect nature. Attempting to recover waste while harming nature itself contradicts the foundation's purpose (G3).	G2, G3 and G6	3
4	We believe that the residents of the district are in the right and argue that this factory should not be built. The main reason for this is that the air and soil pollution caused by the harmful gases emitted by the factory will disrupt the natural balance of the district, threatening the health of the residents, agricultural land and, consequently, their livelihoods. The X Foundation's claim that 'the gases are harmless' is unscientific. Even recycling plants produce gases such as SO_2 and NOx, which can cause acid rain. Filter systems can only reduce this effect, not eliminate it. Therefore, it is unrealistic to say that they are 'harmless'. Furthermore, even if recycling is achieved, this benefit is negligible compared to the damage caused to the environment and people. Factories are man-made structures and inevitably disrupt the natural environment. This is because the construction of a factory alters the natural terrain and vegetation, while its operations lead to increased energy consumption, wastewater, and carbon footprint. In a place like Doğalcık District, which possesses natural and historical values, such damage cannot be tolerated (G4).	G4 and G7	2

Table 8 shows that no group presented arguments at Level 0 or Level 1. This indicates that the pre-service science teachers made minimal claims and defended their claims with at least one justification. The arguments of Group 1 and Group 5 were at Level 2. These groups supported their claims with justifications when presenting their arguments. For example, Group 1 states that the factory will harm the environment and that gas emissions will be harmful, but does not provide supporting or refuting evidence. The arguments of Groups 2, 3 and 6 are seen to be at Level 3. At this level, the claim, justification and supporting arguments are present, and 3 groups developed arguments at this level. For example, participants in Group 3 stated that the gases emitted from the factory are harmful and will affect the environment, but they have created a stronger argument by providing additional information to support these claims. At the highest level, level 4, there are arguments that include claims, justifications, supporting and refuting arguments. Groups 4 and 7 have presented arguments at this level. For example, Group 4 presented their views that the factory would harm the environment and disrupt the natural balance, supporting their argument with a counterargument that the factory could damage the natural environment despite its claim to support recycling.

Discussion and Conclusion

This study aimed to determine how argument-based teaching methods affect pre-service science teachers' understanding of acid rain and to identify their argument levels on the subject. To this end, a questionnaire consisting of five open-ended questions was administered to pre-service science teachers before and after the teaching. The results obtained from the pre-service science teachers' responses to the open-ended questions before and after instruction are presented below. Furthermore, the results of the argument analysis of the groups in the socio-scientific argumentation activity are presented in this section.

Prior to instruction, the pre-service science teachers were unable to explain the formation of acid rain. In order for the teacher candidates to provide a scientifically acceptable answer, they needed to: (a) know the basic gases involved in the formation of acid rain (SO_2 and NOx), (b) the reaction of these gases with oxygen and water vapour in the atmosphere, and (c) the acids (HNO_3 and H_2SO_4) formed after these reactions (Babuçcu, 2016; p.964). However, the pre-service science teachers did not mention the HNO_3 and H_2SO_4 gases formed as a result of the reaction of the basic (SO_2 and NOx) gases with oxygen and water vapour in the atmosphere. Furthermore, the pH value of acid rain is 5-6 due to the carbonic acid present in the atmosphere (Kant & Kızıloğlu, 2003). The pre-service science teachers did not provide any explanation regarding this information. This situation indicates that pre-service science teachers have limited knowledge about acid rain prior to teaching. Similar findings exist in the literature (Babuçcu, 2016; Köklükaya & Güven Yıldırım, 2016; Majer et al., 2019). Research conducted by Majer and colleagues showed that many students had insufficient knowledge about specific pollutants responsible for acid rain, such as NOx and SOx. After the training, the explanations of the majority of pre-service science teachers regarding the formation of acid rain became more scientific and specific. When explaining acid rain, pre-service science teachers mentioned the role of fossil fuels, the chemical processes of acid rain, and its relationship with pH value. This indicates that after the argumentation-based teaching process, pre-service science teachers better understood the chemical processes of acid rain and its connection to fossil fuels.

Regarding the gases that cause acid rain, the pre-service science teachers mentioned gases such as $SO_2(g)$, $SO_3(g)$, (SOx), $NO_2(g)$, $CO_2(g)$, CO(g), and chlorofluorocarbons (CFCs) before the training, but after the training, they only mentioned $SO_2(g)$, $SO_3(g)$, (SOx), $NO_2(g)$, and $CO_2(g)$. After teaching, it was observed that the pre-service science teachers' misconceptions about gases such as chlorofluorocarbons (CFCs) and CO(g) causing acid rain had disappeared. Pabuçcu (2016) determined that students saw CO2 gas as one of the main causes of acid rain, while Ürey et al. (2011) determined that teacher candidates mentioned carbon monoxide, nuclear waste, and chlorofluorocarbon (CFC) gases among the gases that cause acid rain. These results demonstrate that the teaching process is effective in reducing misconceptions about the subject and increasing scientific accuracy.

Regarding the impact of acid rain on the environment, 40.8% of pre-service science teachers mentioned the corrosive effect of acid rain on historical artefacts before instruction. However, this percentage decreased to 27.8% after instruction. This decrease may indicate that, after the teaching process, pre-service science teachers began to approach the environmental effects of acid rain from a broader perspective and that their awareness of other environmental areas, in addition to historical artefacts, increased. Before teaching, 36.36% of pre-service science teachers stated that acid rain harms the soil and reduces its fertility. After the teaching process, this rate decreased to 33.3%. Although these rates remained close to each other, the pre-service science teachers provided more detailed explanations about the chemical structure of the soil after the teaching process. Before the teaching process, 13.65% of the participants stated that acid rain polluted underground resources, while after the teaching process, this rate increased to 33.3%. This increase indicates that pre-service science teachers' awareness of the effects of acid rain on water resources significantly increased after the teaching process. The percentage of pre-service science teachers who mentioned toxic effects, which was 9.1% before teaching, rose to 38.9% after teaching. After the training, pre-service science teachers mentioned that acid rain could have toxic effects on living organisms and could also damage the respiratory and immune systems. This suggests that pre-service science teachers gained more knowledge about the biological effects of acid rain as a result of the training. Similar findings regarding students' views on the environmental impact of acid rain are available in the literature (Buldur et al., 2018; Çelikler & Harman, 2015; Demirbaş & Pektaş, 2009).

Regarding the impact of acid rain on living organisms, 69.23% of pre-service science teachers mentioned the negative effects of acid rain on human health before the training. After the training, this rate decreased to 21.43%. Pre-service science teachers also focused on other environmental and ecological effects of acid rain after the training. Before the training, 23.08% of pre-service science teachers mentioned that acid rain negatively affected biodiversity. However, after the training, no opinions were expressed in this category. This situation may stem from the training process directing pre-service science teachers towards more general ecosystem and habitat effects rather than biodiversity. The view that acid rain negatively affects the ecosystem was expressed by 7.69% of pre-service science teachers before teaching and 7.14% after teaching. Pre-service science teachers generally stated that acid rain could have harmful effects on plants by disrupting the chemical structure of the soil. 71.43% of pre-service science teachers stated after the training that acid rain disrupts the habitats of living organisms. Overall, it is seen that after the training, pre-service science teachers evaluated the effects of acid rain from a broader environmental perspective rather than solely in the context of human health. Similar findings regarding student views on the effects of acid rain on living organisms are available in the literature (Babuçcu, 2016; Buldur et al., 2018; Ürey et al., 2011).

Regarding the prevention of acid rain, the most frequently emphasised view before teaching was the necessity of installing filters on factory chimneys, with 47.1% of pre-service science teachers expressing this view. After teaching, this view rose to 57.14%. The idea of using renewable energy sources was expressed by 17.7% before the training, while this figure rose to 42.86% after the training. The training process appears to have increased awareness of environmentally friendly solutions, particularly the use of filters and renewable energy sources. In contrast, suggestions regarding public awareness and the use of public transport and bicycles were not expressed after the training. However, there was a decrease in some categories such as transport and awareness, which may indicate that pre-service science teachers focused on different solutions. At the end of the training, measures that directly affect the environment, such as the use of renewable energy sources and the installation of filters, came to the fore. These findings show that active teaching methods such as environmental education and argumentation increase pre-service science teachers' capacity to develop solutions to environmental problems and contribute to more conscious thinking. Köklükaya and Güven Yıldırım (2016) stated that pre-service science teachers did not have sufficient knowledge about the measures that could be taken to mitigate the effects of acid rain. Kıryak and Özdilek (2019) stated that among the suggestions made by eighth-grade students to prevent acid rain, the most common were the use of public transport and the installation of filters on factory chimneys.

Summers et al. (2001) investigated the understanding of primary and secondary school students in the UK regarding environmental issues, including acid rain. They found that most students believed acid rain was caused solely by car pollution or was directly linked to visible acid in the rain. The researchers suggested that students' misconceptions stemmed from the lack of clear teaching of the chemical reactions involved in acid rain formation, recommending that the science curriculum include clearer and more detailed explanations of pollution sources and chemical processes. Ramadhani et al. (2022) investigated the effectiveness of augmented reality-based learning environments in teaching about acid rain, emphasising that innovative educational tools can enhance students' engagement with and understanding of complex environmental issues. This indicates the need for practical experiments in chemistry education to demonstrate the principles of acid rain and its effects on the environment. Such experiential learning opportunities can enhance students' understanding of acid rain by helping them relate theoretical knowledge to real-world applications (Goss, 2003). Khalid (2003), stating that the lack of context-based learning contributes to the disconnect between theoretical knowledge and real-world applications, indicates that real-world environmental case studies should be integrated into science lessons to develop conceptual understanding. Furthermore, discussion environments that relate theoretical knowledge to real-world applications in these lessons will enable students to better understand abstract and complex concepts. Collaborative learning environments have also been shown to positively influence students' concepts about acid rain. Marinopoulos and Stavridou (2002) found that students' understanding of acid rain improved significantly when they participated in collaborative discussions. This suggests that fostering a collaborative classroom atmosphere can develop students' critical thinking and problem-solving skills regarding environmental issues. In teaching the topic of acid rain, interdisciplinary teaching that combines chemistry and environmental science should be encouraged to better contextualise acid rain within ecological systems. Özcan and Demirel (2019) recommend organising field trips to authentic learning environments such as botanical and ecological gardens, factories, and industrial facilities as part of environmental education. Bulduk (2024) states that, considering the resources available to schools, teacher candidates should be presented with examples of enriched activities that combine different methods and techniques. In this regard, it is recommended that these methods be combined and disseminated in teacher education to develop a more effective approach to environmental issues.

When examining the argument levels of the groups regarding acid rain, it was determined that they wrote arguments at levels 2 and 3. This situation demonstrates that pre-service science teachers use argument components such as supporting evidence, justification, backing and refuting arguments when defending their claims regarding acid rain.

In light of the results obtained, it is evident that innovative teaching methods and more comprehensive environmental education programmes are necessary and important to increase the level of understanding of acid rain as an environmental issue among students and pre-service science teachers. It has been found that argument-based teaching methods on acid rain enable students to better understand scientific concepts and develop their environmental awareness and critical thinking skills. The use of active learning methods such as argumentation in teacher training programmes will ensure that teacher candidates have sufficient knowledge on environmental education topics, enhance their critical thinking skills, and develop their understanding of the subject. It is anticipated that the wider application of this method in science education will increase student achievement and scientific literacy. Therefore, it is recommended that argumentation-based activities be planned and implemented both in science classes and in subject-specific training courses for pre-service science teachers. Furthermore, by using the argumentation method, pre-service science teachers will be able to create learning environments based on scientific discussions and easily manage scientific debates when they become teachers.

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