



# Uncovering the Middle School Students' Reasonings About Multiple-response Nature of Scientific Questions Through an SSI-based Education\*

Ayşe Nur KESKİN<sup>1</sup>, Ahmet KILINÇ<sup>2</sup>

<sup>1</sup> Bursa Uludağ University, Faculty of Education, Türkiye, aysenurrparlak@gmail.com,  
<http://orcid.org/0000-0003-3278-9619>

<sup>2</sup> Bursa Uludağ University, Faculty of Education, Türkiye, akilinc@uludag.edu.tr,  
<http://orcid.org/0000-0003-1906-8454>

Received : 15.02.2025

Accepted : 08.08.2025

Doi: <https://doi.org/10.17522/balikesirnef.1640645>

---

*Abstract* – The purpose of the present research was to find the response to the research question, ‘What is the nature of middle school students’ reasonings about multiple response nature of scientific questions through an SSI-based education?’. We uncovered the development of these reasonings through an SSI-based education where the students encountered context-based instructional activities such as open-ended inquiries, experiments, moral argumentations. For this purpose, we uncovered 15 5<sup>th</sup> grade and 24 8<sup>th</sup> grade students’ reasonings about the multiple response nature of scientific questions using specifically designed Vignettes. In the data analysis, we thematically grouped the students’ reasonings using content analysis procedures. The results showed that students used either phantasy-based or data-based reasoning about the multiple response nature of scientific questions. In addition, we noticed that students used a range of sub-reasoning types (e.g., problematic induction, excessive imagination, best argument epistemology, conditional relativity, etc.) under these two main reasonings. These reasoning types could be used as a rubric for understanding students’ perspectives regarding NOS within SSI contexts.

*Keywords*: Nature of science, multiple response nature of scientific questions, middle school students, SSI-based education.

-----  
Corresponding author: Ayşe Nur KESKİN, aysenurrparlak@gmail.com

---

\*This article is derived from the first author’s master’s thesis completed at Bursa Uludağ University.

## **Introduction**

Science is a human activity that is based on finding the responses to the questions regarding the mechanisms behind natural events (Sanitt, 1996). Within this questioning activity, the process in all of the scientific fields is started with a question and completed with multiple responses (Johnston & Southerland, 2001). These responses are achieved either at the same time or in the course of time (Johnston & Southerland, 2001).

This multiple-response nature of scientific questions has attracted the attention of some philosophers. Comte (1830/2015), for example, does not believe that one scientific question would have multiple responses. He believes that positive science includes only the absolute notions that are based on observations and experience. In addition, Bacon (1620/2012) has built his notion on inductivism, and he believes that multiple responses may stem from the fact that scientific approaches experience fundamental renewals due to new findings (i.e., observations and experiments) produced in the course of time. In the case of Popper (1934/2017), he believes that scientific questions always have multiple responses, and the duty of scientists is to decrease the number of these responses by critiquing existing responses (i.e., falsification process). He believes that scientists produce counter-examples for existing responses in order to reach the best responses even if these responses will also undergo the same process over time. From a more sociological perspective, Kuhn (1962/2017) believes that multiple responses stem from multiple paradigms that are based on different camps of scientists with different beliefs, values, and methodologies and that have emerged over time. He believes that, in the course of time, scientific activities consistently experience two follow-up stages: i) the normal stage and ii) the revolutionist stage. Firstly paradigmatic knowledge has a cumulative nature and is produced by puzzle-solving-like developments. Secondly, emerging uncertainties resist the existing paradigm/response, and another paradigm/response is produced by revising the previous one. In the case of Ravetz (2012), science has experienced a post-normal stage in the last decades. Post-normal science is different from normal science, which was emphasized by Thomas Kuhn. Normal science progresses through puzzle-solving stages, whereas post-normal science, which is conducted particularly within complex humanistic problems such as global warming, cancer, and the Coronavirus pandemic, works under uncertainties. In addition, while values are not used in the decision-making stages of normal science, they are explicitly shared in the post-normal one. In addition, the knowledge is evaluated by the scientists in normal science, whereas it is assessed not only by the scientists but also by the public, media, politicians, and other stakeholders in

post-normal science. Therefore, in post-normal contexts, there is a range of responses for the same scientific question due to the different value systems of the stakeholders, and the responses that have not only genuine empirical justifications but also social consensus are better than the other alternatives.

In addition, the multiple-response nature of scientific questions has drawn considerable interest from science educators, considering that the Nature of Science (NOS), understanding of science from philosophical and historical perspectives, is a critical part of scientific literacy in recent science education reforms and documents (e.g., Next Generation Science Standards [NGSS] Lead States, 2013; Council of Ministers of Education Canada [CMEC], 1997). Within these documents and reforms, even if there are still uncertainties regarding how science should be represented and which tenets of science should be taught (e.g., Allchin, 2011; Irzik & Nola, 2011), we can argue that the ‘consensus view’ of Lederman’s team, who tried to fuse some philosophical considerations (i.e., Bacon, Kuhn, and Popper) up, is the most accepted model (Abd-El-Khalick, 2012). Within this model, the multiple-response nature of scientific questions is emphasized in different tenets. In the tenet of ‘empirical nature of scientific knowledge’, for example, the researchers argue that different theoretical frameworks and perceptual situations filter the observations that are the main justification components of science, which may result in different responses to the same question. In the tenet of ‘distinction between scientific theories and laws’, theories are particularly described as the inferred explanations for the observed phenomena; therefore, multiple theory/response production might be the result of diverse inferences. In the tenet of the ‘creative and imaginative nature of scientific knowledge,’ it is believed that scientists’ creativity and imagination are as important as the observations, and the diversity within such mental tools may result in the diversity within the responses. In the tenet of ‘theory-laden nature of scientific knowledge,’ the researchers argue that scientific investigations include prior works, theories, beliefs and experience; therefore, the diversity within such historical background may be one of the reasons for multiple responses. In the tenet of ‘social and cultural embeddedness of scientific knowledge’, the idea that science, as a humanistic activity, is influenced by social and cultural factors (e.g., power structures, socioeconomic factors, religion, etc.) may be another reason for multiple responses. In the tenet of the ‘myth of the existence of a scientific method,’ the researchers believe that there is no sequence of scientific activities such as observing, testing, measuring, constructing theories and so on or a single scientific method; therefore, the diversity within the methodologies may result in multiple

responses for the same scientific question. In the tenet of 'tentative nature of scientific knowledge,' it is argued that scientific claims change as a result of new evidence, advances in the technologies and reinterpretation of data. This situation also contributes to the development of multiple responses (Abd-El-Khalick, 2012; Lederman et al., 2002).

By adopting these tenets, the science education researchers (e.g., Lederman et al. 2002) have developed interview forms in which they have asked questions about these tenets in order to uncover the participants' beliefs about NOS. They, for example, ask what science is, what makes science different from religion and philosophy, the necessity of experiments for producing scientific knowledge, the changeability of theories over time, the distinction between theories and laws, the certainty of knowledge regarding specific examples (e.g., the structure of atoms, taxonomy of species, etc.), the tentativeness of scientific knowledge (e.g., about dinosaur extinction), whether social factors influence science, or it is universal and the creative and imaginative nature of investigations. After producing the interview transcripts, the researchers have classified the responses/beliefs for all of the tenets using the following two categories: 'naïve' and 'sophisticated'. Sophisticated beliefs have particularly emphasized the multiple-response nature of scientific questions in all of the tenets. On the other hand, naïve beliefs are based mostly on one clear response to one scientific question (e.g., Abd-El-Khalick, 2012). Similarly, in this research these tenets were used in order to uncover students' reasoning about nature of scientific questions.

## **Literature Review**

Using these interview forms, McComas (1996), for example, proposed some myths about NOS that are common among school students and that may be one reason for single-response situations. Some of these myths are: 1) a general and universal scientific method exists, 2) evidence accumulated carefully will result in sure knowledge, 3) science and its methods provide absolute proof, 4) science is procedural more than creative, 4) science and its methods can answer everything, 5) scientists are particularly objective, and 6) all work in science is reviewed to keep the process honest. Similarly, Deve and Küçük (2016) argued that some seventh-grade students considered scientific knowledge to be certain. In addition, Doğan and Özcan (2010) argued that some seventh-grade students considered that because the natural facts did not change, the theories and laws about them would not change. Similarly, Solomon et al. (1992) found that some middle school students considered the theories to be facts. In another similar study, Eastwood et al. (2012) found that some high school students considered that scientific theories definitely did not change. According to them, a theory is

something that's been proven time and time again by many people, and when done the correct way, it always results in the same conclusions.

On the other hand, Yenice et al. (2018) noticed that some high school students were aware of the multiple-response nature of scientific questions and possessed sophisticated NOS beliefs. These students emphasized the changeable nature of scientific knowledge and the importance of subjectivity, creativity, and imagination in science. In addition, Çetinkaya (2019) argued that most of the sixth-grade students were aware of the tentative nature of science. These students particularly gave examples emphasizing the changes in the scientific models and the theories over the course of time. Similarly, Deve and Küçük (2016) found that some seventh-grade students argued that scientific knowledge could change if new evidence were found and it had a falsifiable character.

In addition, some researchers used socioscientific issues such as GM Foods and nuclear plants to contextualize NOS tenets. They have explored specific aspects of the relationship between NOS and SSI by identifying NOS components (e.g., tentativeness, creativity, subjectivity, theory, and law, etc.) in the ill-structured problems (Karisan & Zeidler, 2017) because they believed that the SSI-based environments could provide optimum contexts to develop students' perspectives about NOS (Khishfe, 2022). Perhaps because of SSI's difference from normal scientific contexts (in the Kuhnian sense) in terms of their epistemic nature (Ravetz, 2012), these researchers found some extra dimensions within the reasonings of students about the multiple-response nature of scientific questions. Although NOS broadly and commonly entails topics such as the ontological and epistemological underpinnings of science, what science is and is not, how science and scientists work. The relationship between science and society, it is argued academically in how NOS should be framed, taught, and assessed, which impacts the role NOS plays in SSI engagement (Herman et al., 2023). Sadler et al. (2004), for example, analyzed the students' responses as to how groups of scientists evaluating the same SSI data could produce divergent conclusions. The researchers produced four groups of responses: 'myth confusion,' 'data concerns,' 'beliefs and opinions,' and 'different foci'. In the 'myth confusion' group, the students considered that some scientists' responses were based on facts and some on myths. Regarding 'data concerns', some students emphasized that some scientists used different data in their interpretations. In addition, some students argued that some scientists used different data analysis techniques. In the case of 'beliefs and opinions', the students considered that scientists might reach different conclusions because of their beliefs and opinions about the SSI subject. Regarding 'different

foci', the students believed that the reason for the multiple responses might be different focus points and research questions that scientists used. In addition, Karpudewan and Roth (2018) investigated 12-year-old students' reasoning skills about SSI and the impact of an SSI-based education on these skills. They found that some students made intuitive decisions about these issues. They either used spontaneous responses (e.g., water pollution is dangerous) or claims without concrete evidence. On the other hand, after the intervention, they noticed that these students increasingly used evidence-based decisions (e.g., Illegal logging destroys the animals' habitats and the plants go extinct and are endangered) because they used explicit and concrete evidence. In addition, Sutter et al. (2019) investigated the relationship between 6<sup>th</sup>-grade students' thinking style (level of abstraction) and their perceptions (positive, negative, or neutral) about an SSI case (wind turbines). It was found that students who had negative perceptions about wind energy added more concrete problem statements and more observable examples. Generally, students who problematized the issue more concretely added observable actions with little additional interpretation. In contrast, students who had abstract thinking provided more additional interpretation related to theoretical, spatial, social, and temporal aspects (Cian, 2020; Kinslow et al., 2018).

### **Summary, Research Purpose, and Research Questions**

Science is a questioning activity that starts with a question and results in multiple responses. Previous research shows that there are three main reasons for the response nature of scientific questions. Firstly, consistent with the positivity ideology of August Comte (1830/2015), some school students believe that there is an unchangeable single response to one scientific question. It was found that particular positivist beliefs, such as science can respond to every question, were responsible for this argument (e.g., Doğan & Özcan, 2010; McComas, 1996). In the second, some school students believed that there are different responses to the same scientific question due to different methodologies and approaches. Some also believed that one of these responses might be better than the others. Consistent with the arguments of Bacon (1620/2012), Kuhn (1962/2017), and Popper (1934/2017), they believed that scientific questions lead to multiple responses due to methodological, theoretical, analytical, and background-oriented differences and the best responses supported by the reasonable evidence and empirical procedures can be accepted to the scientific community (e.g., Deve & Küçük, 2016; Yenice et al., 2018). In the third, consistent with the arguments of Ravetz (2012), some students considered that there are different responses for the same socio-scientific question due to different value systems and that one that is

consistent with their value systems was the correct response. The students possessing strong negative beliefs or using intuitive decision-making modes about SSI cases (e.g., Karpudewan & Roth, 2018; Sutter et al., 2019), for example, seem to easily reach single responses that are consistent with their value and decision systems.

Taken together, even if the researchers use different terminologies and classifications (e.g., naïve & sophisticated, intuition-based & data-based, etc.) (Abd-El-Khalick, 2012; Karpudewan & Roth, 2018), we can argue that there may be two reasoning types about multiple response nature of scientific questions: i) phantasy-based reasoning, ii) data-based reasoning. Firstly, even though there is a lack of evidence, some students easily complete the incomplete data with their beliefs and values via their imagination and reach a single response. First and third reasonings that emerged in the literature review could be collected under this reasoning. Firstly, the students benefit from their positivistic beliefs about science, such as the aim of science is to reach single responses or science can answer every question. Thirdly, they use their ecological, technological, economic, and other social/humanistic values in socio-scientific contexts, and these values make them easily reach some single conclusions that are consistent with their value systems. Even if these beliefs and values seem to be somehow related to the context, it seems that the students put some imaginative mental effort into connecting them with the context even though there is no such direct relationship. On the other hand, in data-based reasoning, the students seem to stick with the data and knowledge production processes. They seem to be aware of the incomplete data and the multiple nature of variables, methodologies, and approaches. Using this awareness, some of them think of the best arguments that are strongly supported by existing evidence in those specific conditions. The second reasoning that emerged in the literature review above could be collected is data-based reasoning.

In the introduction section, using the philosophical considerations and empirical findings in the literature, even if we relatively conducted a thematic reduction by producing two main reasoning types about the response nature of scientific questions, this reading-oriented speculation required empirical findings. At this point, the purpose of the present study was to uncover the nature of middle school students' reasonings about the multiple response nature of scientific questions. For this purpose, we aim to test the availability of two main reasoning types (i.e., phantasy-based and data-based) using real cases (i.e., 15 5<sup>th</sup> grade and 24 8<sup>th</sup> grade students' reasonings about two socio-scientific contexts), the components and mechanisms building these reasonings and the development of these reasonings through

an SSI-based education. We believe that such a test is important because it has the potential to make science educators have clearer classifications about NOS reasonings than those in existing frameworks by producing relatively appropriate diagnostics. In addition, considering the importance of directing students from naïve reasonings through more sophisticated versions of NOS (emphasized by the national and international science education reform documents), we tested these diagnostics tools in order to uncover the nature of the development of these reasonings through an SSI-based education.

Taken together, the following research question and its sub-versions guided our research inquiry:

**Research Question 1.** What is the nature of middle school students' reasonings about the multiple-response nature of scientific questions through SSI-based education?

## **Method**

### **Research Design**

A qualitative research design was adopted for this study to uncover students' reasonings about multiple responses to the same scientific question. This design was based on an interpretive approach (Creswell, 2017) with a naturalistic inquiry philosophy (Lincoln & Guba, 1985).

### **Project Context**

In the present study, the data from the project 'Educating science teachers about teaching socioscientific issues: A learning community study' were used. The project covered four stages. In the first stage, the literature review about SSI, deep interviews with the scientists regarding specific SSI examples, and a Delphi study with experienced science teachers and science educators were conducted, and this knowledge was fused up by an epistemic amalgam in order to develop a curriculum for SSI units. This curriculum covered an inquiry-based argumentation-oriented teaching vision, the learning areas that are based on 'searching for the data', 'thinking of the data', and 'believing or disbelieving', and the learning goals such as 'evaluating the justification processes of the evidence' and 'knowing the problems and misunderstandings in the development of evidence'. Therefore, the framework was particularly based on the epistemic development of the students by focusing on the data/evidence development processes. In the second stage, this framework informed four teaching modules that are developed based on specific SSI contexts and that target specific teaching units in the middle school science curricula from grades 5 through 8. In the

third stage, an in-service science teacher education was planned for nine teachers in the same school so that these teachers could apply the curriculum for SSI using the developed teaching modules. Within this education, the nature of knowledge, the relationships between knowledge and belief, the justification processes, and the nature of SSI and SSI teaching were discussed. In addition, these teachers came together in the learning community meetings in order to discuss their experience and get feedback from the project team in order to resolve the problems and improve their education. In the final stage, the effectiveness of the whole project was tested within real classrooms of these trained science teachers. For testing the effectiveness of SSI-based education, four vignettes (one for each grade) covering SSI scenarios and discussions among the experts and representatives of the public were developed. These vignettes were applied to the school students in both control (where traditional teaching methods and science textbooks were used) and experiment (where the developed curriculum for SSI and developed teaching modules were used) groups as pre and post-tests.

### **Sampling**

In the present study, we focused particularly on the data from these vignettes in the experiment groups of 5<sup>th</sup> and 8<sup>th</sup> grades. Because the purpose of the present study was to uncover the nature of school students' reasonings about multiple response nature of scientific questions, it was considered that these reasonings and their development could efficiently be pursued through an SSI-based education in the experiment groups (e.g., Karpudewan & Roth, 2018). On the one hand, the literature shows (e.g., Sadler et al., 2004) that SSI-based contexts are strong environments where NOS beliefs and reasonings could efficiently be uncovered. On the other hand, like the other NOS-fostering learning environments such as explicit NOS teaching (Çetinkaya, 2019) and history of science education (Rudge et al., 2014), SSI-based education target scientific epistemic development (i.e., the development in NOS beliefs and reasonings) (e.g., Zeidler & Kahn, 2014); therefore, it has potential to develop these reasonings. The students in this education program, which covered five weeks, experienced open-ended inquiries, many experiments, moral argumentations, decision-making activities, evaluations of media reports. In addition, the teachers adopted dialogic teaching where they shared their authority with the students, asked students to justify their responses, made students relate their arguments with one another's. In addition, considering the qualitative nature of the present study, we limit our coverage to two experiment groups out of nine. In addition, we selected grades 5 and 8 in order to uncover possible age-oriented patterns.

In the selected 5<sup>th</sup> grade experiment group, there were 33 students. All of these students completed the 5<sup>th</sup>-grade vignette as the pre-test; however, 28 out of them completed the same test as the post-test. In addition, taking a closer look at the written statements in the pre-post vignette couples, we decided to exclude 13 students' data because of the limited writing and unresponded sections. In the end, we used the data of 15 5<sup>th</sup>-grade students in one of the experiment groups. In addition, eight of them were males, and seven of them were females.

When it comes to 8<sup>th</sup>-grade students, there were 33 students in the selected classroom. All of these students completed the 8<sup>th</sup>-grade vignette as the pre-test; however, 32 of them completed it as the post-test. In addition, we excluded the data of eight students due to limited writing or unresponded sections. Therefore, we used the data of 24 8<sup>th</sup>-grade students in the selected experiment classroom in the present study. In addition, 12 of them were males, and 12 of them were females. Students were coded as grade level, letter, and order of student (i.e. 5G1 or 8G2)

### **Data Collection Tools**

Two vignettes – one for 5<sup>th</sup> grade and the other for 8<sup>th</sup> grade – were used as the data collection tools in the present study. Both of the vignettes included one authentic SSI case covering one scientific question and multiple follow-up responses due to incomplete data. At the end of these vignettes, the same question ‘We see that scientists (biologists in 5<sup>th</sup> grade vignette and biology professors in 8<sup>th</sup> grade vignette) have different views about SSI case (about the cause of diseases in children in 5<sup>th</sup> grade vignette and about the effects of farming around the lake in 8<sup>th</sup> grade vignette). In your opinion, wouldn't a question have a single response in science? Explain your response.’ was asked with slight changes, and blank places were given so that the students could write their responses. These vignettes were developed by the project team, which included two science education professors and five post-graduate students in science education.

**5<sup>th</sup>-grade Vignette:** In the introduction section of the vignette, a health-oriented problem in a village (an illness among the children) was presented. According to the scenario, a detergent factory was established five years ago, and there has been a problem for two months. The district governor, headman, a resident of the village who works in the factory, a biologist who searches about environmental problems in the region, and another biologist who is an employee in Family Health Centre came together in order to find the reason for the problem. Their thoughts and discussions about the situation were given in the vignette.

**8<sup>th</sup>-grade Vignette:** In the introduction section of the vignette, a health-oriented problem in a village (mortality of heron eagles) was presented. According to the scenario, the village was settled around a lake, and there is a rich ecosystem in the lake. Villagers have recently observed that many heron eagles have died and expressed the situation to the district governor. The district governor brought together a resident of the village, a headman, and two Biology professors working in the region. Their thoughts and discussions about the situation were given in the vignette (Both of the vignettes were added in the Appendix).

Even if we benefit from one vignette for one of the grades and one another for the other, the epistemic structure of the scenarios was almost the same, considering the fact that the resident, the manager, and two scientists in both of the scenarios strive to find the reason/s for the problem in the village. In addition, two scientists in the vignettes suggested different responses, and one compared his/her ideas and data with the other's. In addition, because the vignettes were developed to test the effectiveness of the SSI-based education (i.e., the project), the subjects in the vignettes were consistent with the teaching units taught in the experiment groups. These units were 'Ecosystem and Food Chain' in 5<sup>th</sup> grade' and 'Nature and Environmental Pollution' in 8<sup>th</sup> grade. Therefore, the subjects were also similar in terms of their epistemic and value-oriented nature.

### **Data Analysis**

In order to thoroughly classify and compare the students' responses, we transcribed students' written statements in the vignettes and compiled them into an Excel file. Two independent researchers (two authors) independently read all of the statements two times and then initiated a constant comparative method (Lincoln & Guba, 1985) in order to group the statements together. In these prolonged discussions, they pursued four stages that emerged during the data analysis.

First, they brought the sentences representing 'one reasoning about multiple response nature of scientific questions' together. At this stage, some external sentences that are not related to building a conclusion (i.e., production of reasoning) are excluded.

After selecting the sentence groups representing the reasonings, in the second stage, it was decided to group the reasonings under the themes such as 'phantasy-based reasoning' and 'data-based reasoning'. In phantasy-based reasoning, we put together the reasonings that are based on school students' beliefs and values about science (e.g., positivist beliefs and values), ecology, technology, health, and economy and that are imaginatively used in order to

complete incomplete data for reaching one single conclusion. One example here is, 'It is true that chemicals used in agriculture kill eagles. This is why the eagles become extinct rapidly.' In addition, we noticed that some students used some problematic logical inferences, inductions, causal reasonings, and excessive imagination that are not directly related to the context in order to complete incomplete data and reach single conclusion imaginatively. We incorporated these reasonings into the 'phantasy-based reasoning' group too. One example (excessive imagination) here is, 'Children may use water for fun. They battle with water filled with toxic waste battle with water filled with toxic waste, but they do not realize it. For this reason, children may be sick, but the situation may have other explanations. In the 'data-based reasoning', on the other hand, we put together the reasonings, including the comparisons between the scientific responses in terms of data collection, methodologies, validity, reliability, justification procedures, and background-oriented issues. One example here is, 'I do not think there is only one answer because more than one person interprets the question, and some of them are possibly true.'

In the third stage, after classifying the reasonings within pre and post-tests as 'fantasy-based', and 'data-based' and bringing the pre- and post-reasoning couples for each student together, we built the 'developmental themes'. The development here represented the explicit changes in the reasonings.

In the final stage, we used descriptive statistics (i.e., frequencies and percentages) to represent the developmental themes numerically.

### **Validity and Reliability**

For the validity and reliability of the present research, the procedures of naturalistic inquiry (Lincoln & Guba, 1985) were used to some extent. The intervention in both of the experiment groups took about five weeks. A research team, including seven researchers, developed the teaching modules and the vignettes. In addition, the two teachers (one in the 5<sup>th</sup>-grade classroom and the other in the 8<sup>th</sup> grade classroom) in the selected experiment groups were exposed to the same in-service teacher education regarding epistemology and epistemic development. It is considered that this 'long-term' planning and applications may contribute to the credibility of the knowledge produced. In addition, in the data analysis, 'peer assessments' were used, and a 'constant comparative analysis' was adopted. In addition, a 'negative case analysis' was applied to the data in order to determine the classifications.

## Results and Interpretations

Because the developmental themes covered the main reasoning types and their components/mechanisms (sub-reasonings), we presented the developmental themes as the main headings in this section. In addition, we presented example quotations representing each sub-reasoning in the appropriate places and several interpretations as to why these sub-reasonings were collected under one of the main reasoning types following these quotations.

### The Developmental Themes in 5<sup>th</sup> Grade Students

**Table 1** The developmental themes in 5<sup>th</sup> grade students

Developmental themes	Number of students (n=15)	Percentage %	Total percentage %
1. Phantasy based reasoning > Phantasy based reasoning	7	46.6%	46.6%
1a. Problematic induction > Problematic causal reasoning	2	13.3%	
1b. Excessive imagination > Value-based reasoning	1	6.7%	
1c. Problematic induction > Value-based reasoning	1	6.7%	
1d. Problematic logic > Problematic induction	1	6.7%	
1e. Problematic induction > Problematic induction	1	6.7%	
1f. Excessive imagination > Excessive imagination	1	6.7%	
2. Data-based reasoning > Data based reasoning	7	46.6%	46.6%
2a. Best argument epis. > Best argument epis.	2	13.3%	
2b. Multivariate epis. > Multivariate epis.	2	13.3%	
2c. Multiple methods epis. > Multiple methods epis.	1	6.7%	
2d. Multiple approaches epis. > Multiple approaches epis.	1	6.7%	
2e. Falsification > Multivariate epis.	1	6.7%	
3. Data-based reasoning > Phantasy based reasoning	1	6.7%	6.7%
3a. Multivariate epis. > Value-based reasoning	1	6.7%	

Looking at the developmental themes in 5<sup>th</sup>-grade students in Table 1, we can argue that some students did not change their phantasy-based reasoning, some students did not change their data-based reasoning, and one student replaced her data-based reasoning with phantasy-based reasoning through SSI-based education. We presented each development theme in the following section.

#### Phantasy-based Reasoning > Phantasy-based Reasoning

According to Table 1, seven students (46.6 %) did not change their phantasy-based reasoning through the intervention. We presented specific development themes under this development theme in the following section.

***Problematic induction > Problematic causal reasoning.*** Two students (13.3 %) replaced their problematic induction with problematic causal reasoning through SSI-based

education. 5G1, for example, in the pretest, said *I think that science gives us the only answer here: The disease that appears in children stems from environmental pollution. Thus, bacteria grow faster.* 5G1 used a similar expression with some extensions in the posttest by saying that *Increasing minerals (heavy metals) in the body may cause an imbalance in the body. If all bacteria are thrown out (...are killed), the body cannot resist.* As shown in the statements, the available incomplete data seem to trigger his imagination, and he built the relationships between pollution and bacteria growth or between heavy metals and bacteria reproduction even though these direct relationships were not available in the data/text. In addition, in the pretest, he conducted a problematic induction by seeming to be sure of the fact that the reason for the illness was environmental pollution, even though there was no clear (appropriate and enough) evidence from which he could conduct such induction. In the post-test, on the other hand, he seems to build problematic cause-effect relationships by combining two different response alternatives suggested by the scientists. In addition, even if the bacteria growth in the body was suggested as a reason in the text, he suggested protecting the bacteria flora in the body as a precaution or a solution. This reasoning also covers some teleological problems in the students' causal reasoning. In addition, 5G10, in the pretest, said *I think the response to this question is chemical poisoning. Because there is a detergent factory in the village.* 5G10's posttest response was that *I think the ideas are different, but their results are similar. Both of them are the causes of the disease.* Looking at the responses, in the pretest, 5G10 conducted a problematic induction. She was sure that the response was chemical poisoning because of the sharp reason/evidence of the fact that there was a detergent factory in the village. On the other hand, in the post-test, by saying that two response/reason alternatives might produce the illness together, she conducted problematic causal reasoning because such a combination could not directly be deduced from the data/text.

***Excessive imagination > Value-based reasoning.*** One student (6.7 %) replaced his excessive imagination with value-based reasoning through SSI-based education. 5G3, in the pretest, said *Children may use water for fun. They battle with water filled with toxic waste and battle with water filled with toxic waste, but they do not realize it. For this reason, children may be sick, but the situation may have other explanations.* In the posttest, he said *yes, but there was only one answer. There is no more. The detergent factory should be closed for a while if the problems continue, it should be closed completely.* As can be seen, in the pretest, 5G3 used a daily-life example regarding playing children with the polluted water, perhaps because the incomplete data stimulated such an excessive phantasy that could not directly be

deduced from the text. In the post-test, despite the lack of complete data, he perhaps built a direct relationship between the illness of the children and the detergent factory. In addition, his emotive words/phrases such as ‘there is no more,’ ‘...should be closed’, and ‘...should be closed completely’ displayed that he conducted some evaluations based on his protection-oriented values.

**Problematic induction > Value-based reasoning.** One student (6.7 %) replaced her problematic induction with value-based reasoning through SSI-based education. 5G4, in the pretest, said *It is possible (there is only one response). An increase in the cells that are fighting microbes has been observed.* In the post-test, 5G4 said *there seems to be only one answer: Demolition of the detergent factory.* The student had a phantasy-based reasoning in both tests. In the pretest, she directly inducted that the children’s problem was based on the rise in the cells fighting with microbes even though such direct induction was not confirmed by a respective scientist (second biologist) who suggested it. In the post-test, we noticed that she still believed that there was only one response due to the availability of a detergent factory despite the fact that such a direct relationship was not available in the text. In addition, her emotive words/phrases such as ‘there is “only” one answer: “demolition” of the factory’ might show that she conducted evaluations based on her protection-oriented values.

**Problematic logic > Problematic induction.** One student (6.7 %) replaced his problematic logic with problematic induction through SSI-based education. 5G11, in the pretest, said *Maybe because there is an answer to diseases seen in children. If there is no answer to disease, it cannot heal. Moreover, if the disease does not recover, its result may be death.* In the -test, 5G11 said *children have become ill due to microbial contamination of water, and various events have occurred.* Looking at both of the responses, in the pretest, he used the healing process of the children using a problematic logical inference. Even if he considered the fact that there should be one response for health-oriented questions unless it is, the result would be death, and he was not aware of the fact that many illnesses are the results of a combination of many reasons/mechanisms and the solutions to them also covered many components targeting this body of reasons/mechanisms. In the post-test, he conducted a problematic induction by seeming to be sure of the fact that the reason for the illness was microbial contamination even though there was no clear (appropriate and enough) evidence from which he could conduct such an induction.

**Problematic induction > Problematic induction.** One student (6.7 %) did not change his problematic induction through SSI-based education. 5G12, in the pretest, said *I think. I*

would agree with the biologist working in the Family Health Center. For me, it is true what biologists say. In the posttest, she said *I think the children are sick because of the odors. Polluted water affects their health negatively.* As can be seen, in both of the tests, he used phantasy-based reasoning. In the pretest, he accepted the biologist's argument by a problematic induction. Even though the biologist identified some incomplete pieces in the data processing, he found the biologist's argument true without any proper justification. In the post-test, he used another problematic induction because he considered the odors were the reason for the illness even though it could not directly be inferred from the available data.

**Excessive imagination > Excessive imagination.** One student (6.7 %) did not change his excessive imagination through SSI-based education. 5G15, in the pretest, said *I think the filter might not be installed on the factory chimney.* On the other hand, in the post-test, 5G15's response was *Reasons: 1. Factory owners who do not use filters to the chimney 2—throwing toxic water into the river 3. By mixing the poisonous water with natural water, the fountain can take it in and become poisoned.* The student's statements in both of the tests represented phantasy-based reasoning because he excessively used his imagination by emphasizing the factory filters that were not a part of the data/text and that could not directly be deduced from the available data.

### **Data-based Reasoning > Data-based Reasoning**

According to Table 1, seven students (46.6 %) did not change their data-based reasoning through the treatment. We presented specific development themes under this development theme in the following section.

**Best argument epistemology > Best argument epistemology.** Two students (13.3 %) did not change their best argument epistemology through SSI-based education. 5G6, for example, in the pretest, said *I don't think there is a single answer to a question in science. A lot of people have different ideas, and some of them are likely to be true.* 5G6 gave a similar response in the post-test by saying *I don't think there is only one answer because more than one person interpreted the question, and some of them are possibly true.* Looking at the responses, we can argue that 5G6 considered that there were multiple explanations for one scientific question, and one of them was possibly the best one. Similarly, 5G7 did not change her best-argument epistemology. In the pretest, she said that *because biologists cannot be sure, there can be many reasons, and there is no single answer.* In the post-test, she said *I think there can be of many answers. According to the research of biologists and the symptoms, their diagnoses can be correct.* As can be seen, she was sure that biologists might

have different results or opinions, but by further findings and research, they can be sure of one of the possibilities.

**Multivariate epistemology > Multivariate epistemology.** Two students (13.3 %) did not change their multivariate epistemology through SSI-based education. 5G9, in the pretest, said *I don't think so. Because there can be multiple factors, these factors may have different effects. However, sometimes, there can be a single answer to a problem.* Similarly, in the -, - test, she said biologists conduct research and draw a single conclusion, but sometimes, *they can reach more than one result.* Looking at both of the responses, 5G9 considered that multiple cause-effect relationships and follow-up multiple interpretations were crucial in the development of valid and reliable knowledge. In another case, 5G14, in the pretest, said *I think every child has a different structure so that a different disease may be seen in each child.* 5G14' posttest response was that *Each child's body structure may be different.* Looking at both of the responses, 5G14 focused on the available data and knowledge development process and incorporated one possible variable into existing ones that may produce multiple responses.

**Multiple methods epistemology > Multiple methods epistemology.** One student (6.7 %) did not change his multiple methods epistemology through SSI-based education. In the pretest, 5G8 said *I do not think there is a single answer to a problem in science. Because questions (problems) resolved in science can be resolved in different ways and different techniques, for example, if a scientist resolves one question (problem) differently, another can resolve it differently and never use it again.* In the post-test, he did not change his reasoning by saying *I do not think there is a single answer to a problem in science. Because a problem in science can be resolved in different ways and by different techniques. Thus, there is no single answer to a problem in science.* Looking at the responses, we can argue that 5G8 was aware of the fact that different methodologies, research pathways, and research tools/techniques might result in different responses.

**Multiple approaches epistemology > Multiple approaches epistemology.** One student (6.7 %) did not change his multiple approaches to epistemology through SSI-based education. His pretest response was *I think that there is not only one response. It commonly changes according to opinions. One person may have one opinion, and the other may have ten opinions.* He gave a similar response in the post-test by saying *there was no single response, and everyone's opinion was different.* Taken together, 5G2 considered that the response

changed according to people's approaches because different people had different interpretations of the same problem.

**Falsification > Multivariate epistemology.** One student (6.7 %) replaced his falsification with multivariate epistemology through SSI-based education. In the pretest, 5G13 said *I think there is only one answer to everything in science, but it is hard to find the right answer; there is only one right answer within millions wrong.* In the post-test, he said *There could be more than one toxic substance in chemicals coming from the factory, and those substances may have caused different diseases.* Looking at his pretest response, despite the short response, we can argue that he was aware of the nature of the falsification to some extent. In the post-test, he felt the multivariate nature of the disease development even if he benefits from some imagination. However, we can argue that both of the responses were based on the available data.

#### **Data-based Reasoning > Phantasy-based Reasoning**

According to Table 1, one student (6.6 %) replaced her data-based reasoning with phantasy-based reasoning through the treatment. We presented the specific development theme under this development theme in the following section.

**Multivariate epistemology > Value-based reasoning.** One student (6.7 %) replaced her multivariate epistemology with value-based reasoning through SSI-based education. 5G5's pretest response was that *Some sciences may have one response. Other sciences may not have one response. Every science is different.* In the posttest, 5G5 said *I think that the cause of the disease is people's fault. People get sick because they pollute the environment. And many living things die.* Taken together, 5G5 first considered that some science disciplines may have responses that are more than one, even though we believed that she might use the term 'science' instead of the terms 'question' or 'problem.' Therefore, we can argue that she possessed a multivariate epistemology in the pretest. After the treatment, she replaced this multivariate epistemology with a phantasy-based reasoning in which she used several values. Her emotive words/phrases such as 'people's fault', 'people get sick', and 'many living things die' might show that she used her protection-oriented values.

## The Developmental Themes in 8<sup>th</sup> Grade Students

**Table 2** The developmental themes in 8<sup>th</sup> grade students

Developmental themes	Number of students (n=24)	Percentage %	Total percentage %
1. Phantasy based reasoning > Phantasy based reasoning	5	20.8%	20.8%
1a. Value-based reasoning > Value-based reasoning	1	4.1%	
1b. Excessive imagination > Excessive imagination	1	4.1%	
1c. Value-based reasoning > Problematic logic	1	4.1%	
1d. Problematic causal reasoning > Excessive imagination	1	4.1%	
1e. Problematic logic > Problematic logic	1	4.1%	
2. Data-based reasoning > Data-based reasoning	11	45.8%	45.8%
2a. Multivariate epis. > Multivariate epis.	3	12.5%	
2b. Multiple approaches epis. > Best argument epis.	2	8.3%	
2c. Multiple approaches epis. > Multiple approaches epis.	2	8.3%	
2d. Multiple approaches epis. > Multiple data epis.	2	8.3%	
2e. Multivariate epis. > Conditional relativity	1	4.1%	
2f. Multivariate epis.> Multiple approaches epis.	1	4.1%	
3. Phantasy based reasoning > Data-based reasoning	8	33.4%	33.4%
3a. Problematic induction > Best argument epis	2	8.3%	
3b. Excessive imagination > Best argument epis.	2	8.3%	
3c. Problematic logic > Best argument epis.	1	4.1%	
3d. Value-based reasoning > Multiple approaches epis.	1	4.1%	
3e. Excessive imagination > Multiple approaches epis.	1	4.1%	
3f. Problematic induction > Multivariate epis.	1	4.1%	

Looking at the developmental themes in 8<sup>th</sup>-grade students in Table 2, we can argue that some students did not change their phantasy-based reasoning, some students did not change their data-based reasoning, and some students replaced their phantasy-based reasoning with data-based reasoning through the SSI-based education. We presented each development theme in the following section.

### Phantasy-based Reasoning > Phantasy-based Reasoning

According to Table 2, five students (20.8%) did not change their phantasy-based reasoning through the treatment. We presented specific development themes under this development theme in the following section.

**Value-based reasoning > Value-based reasoning.** One student (4.1%) did not change her value-based reasoning through SSI-based education. 8G1, in the pretest, said *I think it might be. Agriculture is important for everyone.* In addition, 8G1 mentioned a similar expression in the post-test by saying *I think if I were the professor, I would allow agriculture. It is beneficial for me and for everyone, and everyone's thoughts are different.* As can be seen, despite the lack of clear data and the short responses, we can argue that she, in both of

the tests, seems to be sure that agriculture was important and beneficial to people, perhaps because she possessed economy-oriented values in this context.

**Excessive imagination > Excessive imagination.** One student (4.1%) did not change his excessive imagination through SSI-based education. 8G14, in the pretest, said *that in my opinion, Professor Arif integrated his own thoughts into the issue. If the ground of the lake is too hard and if it is not getting water, algae due to soil hardness to grow. At the same time, if water is not received, water cannot be returned. There would be eutrophication due to this reason. People do not perceive toxins originating from fish.* When it comes to 8G14's posttest response, he said *I agree with the biologist Nergiz. Because the base of the lake is hard, it would be easy to grow algae. For this reason, the number of herbivorous carp would reduce. In addition, Ms. Nergiz's explanation can be provable logically and scientifically.* As can be seen in the pretest, 8G14 seemed to benefit from his excessive imagination. In order to rebut Professor Arif's argument, he built many unclear relationships between eutrophication that was not available in the data/text, and that could not directly be deduced from the text and the nature of lake ground. In the post-test, he built another similar unclear relationship between algae reproduction and the nature of lake ground.

**Value-based reasoning > Problematic logic.** One student (4.1%) replaced his value-based reasoning with problematic logic through SSI-based education. 8G16's pretest response was *that it is true that chemicals used in agriculture kill eagles. This is why the eagles become extinct rapidly. For this, we have to stop agriculture and get eagles to protect.* 8G16 gave a similar response in the post-test by saying *Mrs. Nergiz proved to Mr. Arif that the causes of the eagles' deaths were chemicals in their blood. There is a chemical in eagles, according to the general solution. (The question is not a math question, there is only one way).* Looking at both of the responses in the pretest, perhaps because of his protection-oriented values, he was sure that the reason for eagle mortality was the chemicals. In the post-test, on the other hand, even if he again suggested chemicals as the reason, he used problematic logic, considering that scientific questions required single responses because they were not like math questions.

**Problematic causal reasoning > Excessive imagination.** One student (4.1%) replaced his problematic causal reasoning with excessive imagination through SSI-based education. 8G19, in the pretest, stated *I think there is only one answer; this is what Mr. Arif says. Because no such thing happened in the past, the bowl should be made, as Mr. Arif says.* In the posttest, 8G19 said *It could be. Mr. Arif says that the floor of the lake is like a bowl and will never be passed, but Mr. Selim says that this farming has been around for a long time, so*

maybe the bowl can pass water by getting thinner in time. Thus, he can conclude that eagles die due to the pesticides passing through the river. As can be seen, 8G19 actively used his phantasy-based reasoning in both of the tests. In the pretest, even though Mr. Arif identified the bowl nature of the lake ground for rebutting the causal reasoning of the other scientist, 8G19 accepted it as a solution for the problem by conducting a teleological problem in his causal reasoning. In the post-test, on the other hand, he combined two response alternatives that may not directly be related to each other by excessively using his imagination in order to reach a single response.

**Problematic logic > Problematic logic.** One student (4.1%) did not change her problematic logic through SSI-based education. 8G25, in the pretest, said *I think there is only one answer. Because no matter how many reasons there are, the result of the event is the same. Let's look at the following example: 1) Ali took a minus for not doing his homework. 2) Ali took a minus because he didn't bring his homework. 3) Ali took a minus because he forgot his homework. There is only one result, even if there are three causes like this example.* In the post-test, she said *I think there is only one answer because even if there is more than one result, the results will come together, and a logical solution will be found.* Looking at both of the responses, it was clear that she built a problematic logic in both of the tests. In the pretest, for example, she considered that even if there were three reasons for the same problem, like in her example about one student taking minus, the result would be the same. Even if her logic was correct, it was not appropriate for the present context. The context included two scientists trying to find the reason for the problem and suggesting different reasons for alternatives. The question at the end of the scenario was as to why these two scientists reached different results rather than the same result. At the end of the intervention, she also seemed to continue her problematic logic.

### **Data-based Reasoning > Data-based Reasoning**

According to Table 2, 11 students ( 45.8%) did not change their data-based reasoning through the treatment. We presented specific development themes under this development theme in the following section.

**Multivariate epistemology > Multivariate epistemology.** Three students (12.5%) did not change their multivariate epistemology through SSI-based education. 8G5's pretest response, for example, was *I think there is no single answer to a question in science. Because I think there may be more than one reason for eagles' dying.* 8G5 gave a similar response in the posttest by saying *I think there cannot be a single answer to a question considering that there*

*are many reasons for the eagles' extinction.* As can be seen, 8G5 stressed that there may be more than one reason/variable for the eagles' mortality by thinking of the incomplete data in the text. In another case, 8G24, in the pretest, said *Each factor can cause major problems. Some results can vary according to surrounding factors.* In the post-test, 8G24 stressed that *an event could have multiple causes. This is similar to a spider web, and the spider establishes a web in a certain location for hunting. However, when its environment is not suitable, it retracts its web. Briefly, there are multiple causes of the incident.* Looking at both of the responses, we can argue that 8G24 thought of the available unclear data and suggested the multivariate nature of scientific questions. In addition, in the pretest, 8G3 said *There may be no one answer to a problem in science because other assets may be affected if we do an activity.* In the post-test, he argued that *There might be of many solutions to a question. A solution may also cause other problems.* These responses can also be considered under the multivariate epistemology because it seems that 8G3 was aware of multiple cause-effect relationships in the scientific mechanisms due to multiple variables.

***Multiple approaches epistemology > Best argument epistemology.*** Two students (8.3%) replaced their multiple approaches epistemology with best argument epistemology. In the pretest, 8G21 said *There is only one answer to the question in science, but the problem is related to interpretation and perspective. Because biology professors have different perspectives, both of them had different results from the event.* In the post-test, 8G21 said *I think that the difference in Professors' comments may be dependent on a little research in the region. If biology professors conduct comprehensive research with a better team, their opinions can be changed. After this is done, if the biology professors' ideas are different, other scientists who are interested in this discipline should be interviewed, and their opinions should be heard. These views are evaluated and must be proven scientifically.* In the pretest, 8G21 argued that the different responses stemmed from the differences in terms of approaches and interpretations. On the other hand, in the post-test, he mentioned that the best argument could be reached by gaining other scientists' opinions and evaluating and proving them. In addition, 8G9, in the pretest, said *No, it cannot be because they talked about different issues.* In the post-test, 8G9 said. *It cannot be because ,larger scale research should be done and scientifically proven.* Looking at the responses, in the pretest, she had multiple approaches to epistemology because she considered that scientists had different focus points, whereas, in the post-test, she argued the necessity of further research in order to justify one of the alternatives better.

**Multiple approaches epistemology > Multiple approaches epistemology.** Two students (8.3%) did not change their multiple approaches to epistemology through SSI-based education. 8G8, for example, in the pretest, said *People care about their own thoughts and think that they are true, so there is no single response in science. Every idea requires a different intelligence.* In the post-test, 8G8 said *I think there should be much thought in science; however, there should be one result, and this result should be applied.* In the pretest, we can argue that 8G8 had multiple approaches to epistemology because he emphasized the richness of the thoughts. Looking at the post-test, even if he argued that there should be one result, he did not consider that this conclusion needed to be justified by the best evidence; therefore, we categorized the post-test response as the multiple approaches epistemology, too. In addition, 8G4, in the pretest, said *There is no single answer to a question in science. Because people have different thinking skills and can have different answers,,* in the post-test, 8G4 said *It could not be (one single response); why would it be? Ultimately, people's brains can work differently and give different answers.* Both of the responses display that 8G4 had multiple approaches to epistemology because she believed that scientists had different thinking skills and thinking types.

**Multiple approaches epistemology > Multiple data epistemology.** Two students (8.3%) replaced their multiple approaches epistemology with multiple data epistemology through SSI-based education. 8G2' s response, for example, in the pretest was *May be. Everyone is right about his/her opinion. There may be many reasons for this. However, you need to come to a single conclusion.* 8G2, in the --test, said *it is difficult to have one single response. Because everyone speaks with the results that they find, everyone can find different results. Therefore, a common conclusion cannot be reached.* Looking at both of the responses, in the pretest, even if 8G2 argued that scientists need to come to a single conclusion despite various approaches, we did not accept this comment as 'best argument epistemology' because he did not express evidence-based perspectives. On the other hand, in the post-test, he emphasized the multiple-data nature of science by arguing that scientists produced different results. In addition, 8G22, in the pretest, said, *"No. Because different results can have different and many reasons. That's why there is no single answer to a question in science."* In the post-test, she said, *"There can be many responses to a question that is always valid, not just in science. Because the views of each person and the results they find through the methods applied are different.* "In the pretest, 8S22 emphasized the multivariate nature of scientific problems. On

the other hand, in the post-test, she focused on the multiple-data nature of science by expressing that scientists reached different results.

**Multivariate epistemology > Conditional relativity.** One student (4.1%) replaced his multivariate epistemology with conditional relativity through SSI-based education. 8G18, in the pretest, said *I think a question in science can have more than one answer because different factors can affect the situation. The case is also an example; whereas a professor defends that chemicals can come from the river, another professor defends that they can only come from the rain.* On the other hand, 8G18 changed his response in the posttest by saying *he thinks there is no single response to a question in science. There are possible questions only in specific conditions. If conditions change, results change.* Looking at the responses, 8G18 was aware of the multivariate nature of science in the pretest. On the other hand, he possessed conditional relativity in the post-test. He considered that the research questions could be asked under specific conditions, and when the conditions changed, the scientific results would change.

**Multivariate epistemology > Multiple approaches epistemology.** One student (4.1%) replaced her multivariate epistemology with multiple approaches epistemology through SSI-based education. 8G10, for example, in the pretest, said *I think there are multiple causes in science. Because nothing depends on one outcome. So, there are multiple results and methods.* In the post-test, she said *Everyone might have different ideas, and of course, we respect their decisions.* Looking at the responses, we can argue that she believed that multiple causes might be responsible for multiple responses in the pretest, whereas she considered that scientists might have different approaches in the post-test.

### **Phantasy based Reasoning > Data-based Reasoning**

According to Table 2, 8 students (%33.4) replaced their phantasy-based reasoning with data-based reasoning through the treatment. We presented specific development themes under this development theme in the following section.

**Problematic induction > Best argument epistemology.** Two students (8.3%) replaced their problematic induction with best argument epistemology through SSI-based education. 8G6's response in the pretest was that they had *become extinct due to the chemicals used for agriculture.* In the post-test, he stressed *that they might have different opinions. However, the question has one answer in terms of science, and we can find the answer. The answer is that which idea is more appropriate in terms of provability.* Looking at the responses, we can

argue that 8G6 had a phantasy-based reasoning in the pretest because she seems to conduct a direct induction using the chemicals as the justification despite the lack of clear data. In the post-test, on the other hand, she emphasized the provability of the alternatives and therefore, exhibited the best argument epistemology. In addition, 8G13's pretest response was. *I guess that Mrs. Nergiz's statement is more attractive, and the reason for that is that heron eagles eat fish in the lake, and the fish may be poisoned due to agriculture.* In the post-test, 8G13 said *I think there is one response because everything is proven and investigated. However the accuracy of knowledge can sometimes be low. For example, they may find it right that heron eagles die from squirrels they eat, but they do not know that. It must be investigated, too.* Even if he emphasized that he had the estimation in the pretest due to a problematic induction, he seems to believe that one of the alternatives might be correct despite the lack of enough and appropriate evidence. On the other hand, in the post-test, he emphasized the nature of the accuracy of knowledge and the necessity of further research, meaning that he had the best argument epistemology.

**Excessive imagination > Best argument epistemology.** Two students (8.3%) replaced their excessive imagination with the best argument epistemology through SSI-based education. 8G15 said *Mr. Arif is right because the local authority says that we have been doing this for years. I think that the acid rain and so on cause this.* 8G15, in the post-test, said *Yes, everything may have a single reason, but we cannot find it by a single experiment or observation. Maybe, we conduct tens and hundreds of experiments to find it, and there is a freedom of thought for scientists. They can speak differently, and everyone must respect this. But when it comes to science, everything has one answer. There may be different trials.* In the pretest, due to a possible excessive imagination, 8G15 emphasized the acid rain as a possible reason even though this reason was not available in the data/text and could not directly be deduced from the text. On the other hand, in the posttest, he changed his response by arguing that scientific progress needed many experiments and observations to reach one of the possible responses. In another similar case, in the pretest, 8G17 said *Mrs. Nergiz says that eagles contain chemicals and thinks these chemicals poison them. However, Mr. Arif thinks that it is not related to agriculture and that rain pollutes the lake water. I think the factories related to agriculture may pollute the air. Acids pollute the air; rain comes back to us as acid rain. So I think both are true. These are two events connected to each other.* In the post test, she said *So it might be a question, but I think it's better to have more than one answer in science. Because scientists consider everything. They have an opportunity to do research,*

*experiment, and so on. Thus, he can give a clear answer to the question (based on these).*

Looking at the responses, using her excessive imagination, 8G17 connected two alternatives and reached the acid rain as the reason for the problem despite there was no such direct relationship within the data/text. However, in the post test, she argued that there is a necessity to have alternatives and justify one of them by research and experiment in order to reach clear answers.

***Problematic Logic > Best argument epistemology.*** One student (4.1%) replaced his problematic logic with best argument epistemology through SSI-based education. In the pretest, 8G23 said *that Mr. Arif said sounded wrong. What does it mean, like the bowl? Mrs. Nergiz's answer is correct and logical: agriculture needs to be moved to another place.* In the post test, he said *it depends on the situation. I think because the truth is found by one more than evidence, there would be more results and new knowledge. Thus, a better result can be found.* Looking at the pretest, he used his phantasy-based reasoning in the evaluation of the two approaches, and he concluded that one of the approaches was correct considering its logical nature. On the other hand, in the post-test, he argued that the result ightmight vary according to the situation and, therefore, much more research and evidence were necessary in order to reach better results.

***Value-based reasoning > Multiple approaches epistemology.*** One student (4.1%) replaced his value-based reasoning with multiple approaches to epistemology through SSI-based education. 8G7, in the pretest, said *I wish that fields were fertilized with natural fertilizers, and they are located a few km away.* In the post-test, 8G7 changed his response by saying *I do not think (there is one single response) because all ideas are collected and then it is decided.* As can be seen, in the pretest, 8G7 used emotive words/phrases such as 'I wish' and 'natural fertilizers', perhaps because of her protection-oriented values. In the post--test; he argued that there would be multiple approaches even though it was necessary to select one of them.

***Excessive imagination > Multiple approaches epistemology.*** One student (4.1%) replaced her excessive imagination with multiple approaches to epistemology through SSI-based education. 8G11, in the pretest, said *I think Mr. Arif is right because if it were about agriculture, the people and the fish would be damaged. Because the ground of the lake is hard, the reason for chemicals is raining.* 8G11's posttest response was *that everyone can have different ideas, and we should respect that. If everybody's thoughts were the same, life would be ridiculous.* Looking at the responses in the pretest, using her excessive imagination,

8G11 concluded that the reason for the problem was raining despite the lack of clear evidence. However, in the post-test, she changed her position and had multiple approach epistemology even though her short response seemed to be out-of-data processing to some extent.

***Problematic induction > Multivariate epistemology.*** One student (4.1%) replaced her problematic induction with multivariate epistemology through SSI-based education. In the pretest, 8G20 said *Sure. In fact, all except Mr. Selim say they are sick, and Mrs. Nergiz explains the issue. So, the only answer is to ban agriculture around the lake.* On the other hand, in the posttest, she said *It cannot be because there can be a lot of problems or solutions that are related to it.* In the pretest, 8G20 was sure that Mrs Nergiz's explanation was correct despite the fact that such a direct induction could not be conducted due to incomplete data. On the other hand, in the posttest, she mentioned that there may be more than one response to a scientific question due to the multivariate nature of natural and scientific mechanisms.

### **Discussion and Conclusion**

The purpose of the present research was to find the response to the research question, 'What is the nature of middle school students' reasonings about multiple response nature of scientific questions?'. For this purpose, we uncovered 15 5<sup>th</sup> grade and 24 8<sup>th</sup> grade students' reasonings about multiple response nature of scientific questions using specifically designed Vignettes that covered one unresponded socio-scientific question due to incomplete data and multiple responses by two different scientists. We also uncovered the development of these reasonings through an SSI-based education. Philosophical (e.g., Comte, Bacon, Popper & Kuhn) and theoretical (NOS and SSI) considerations framed these reasonings. Following section includes a discussion of our conclusions with existing literature.

The present study showed that middle school students used either fantasy-based or data-based reasoning about the multiple response nature of scientific questions. In fantasy-based reasoning, they easily reach a single conclusion by completing the incomplete data by their phantasy-based components that are not available in or directly deduced from the data/text. We noticed that they benefited from one of the following five sub-reasoning types under the heading of fantasy-based reasoning: 1) value-based reasoning, 2) excessive imagination, 3) problematic induction, 4) problematic logic, and 5) problematic causal reasoning. In the 'value-based reasoning', consistent with Ravetz's (2012) arguments, they used protection- or economy-oriented values aroused within the text in order to complement the incomplete data. They benefited from certain emotive words/phrases such as 'beneficial for villagers',

'people's fault', 'demolition', 'natural', and 'should be closed' in their evaluations, and these words show that they firstly approached the issue from moral perspectives rather than epistemic ones. In the 'excessive imagination', on the other hand, some students emphasized several causal mechanisms related to 'water games', 'filters', 'eutrophication' and 'acid rain' that could not directly be deduced from the data/text. Perhaps because of their willingness to reach one single result, they put some extra imagery into place. In the 'problematic induction', they conducted direct generalizations based on insufficient data. These students were sure that one of the scientists' responses was correct despite the lack of clear evidence. They particularly considered that environmental pollution was responsible in both of the cases. In the 'problematic logic', the students either considered that scientific questions must have one response because even if there are different reasons, there must be one result in a logical sense, or they considered that one of the responses was correct because it was logical. Finally, in the 'problematic causal reasoning section, some students either incorrectly combined two responses in the text in order to produce one response or conducted some teleological problems by confusing the causes and effects.

Regarding data-based reasoning, we noticed that these students stuck with the data production process and analyzed the missing pieces and alternatives using their epistemic knowledge about scientific methodologies, validity and reliability processes, and the history of scientific knowledge development. In other words, rather than completing the incomplete data, these students focused on the possible reasons why the scientists could not complete the data production process and could not reach the desired conclusions. Under the data-based reasoning, the students used one of the following seven sub-reasoning types: 1) best argument epistemology, 2) falsification, 3) conditional relativity, 4) multivariate epistemology, 5) multiple methods epistemology, 6) multiple approaches epistemology, and 7) multiple data epistemology. In the 'best argument epistemology', students thought that there were multiple responses for the same scientific question; however, the best response (argument) justified by sound evidence should be chosen. In the 'falsification', on the other hand, consistent with Popper's (1934/2017) terms, students considered that there might be many wrong responses to the same scientific question and that it was important that these wrong explanations should be eliminated to approach the true response. In 'conditional relativity,' students thought that the reason for multiple responses was a conditional change (i.e., responses can change according to existing conditions). In the 'multivariate epistemology', students considered that multiple responses stemmed from multiple variables and multiple relationships among these

variables. In the ‘multiple methods epistemology’, students emphasized the fact that researchers used different methodologies and research tools that could cause multiple responses. In the ‘multiple approaches epistemology,’ students considered that scientists had different approaches and views about a scientific problem,, which could cause different interpretations and multiple responses. Finally, in the ‘multiple data epistemology’, the students argued that the scientists might produce different data and reach different results.

These results showed that middle school students’ reasonings about the multiple response nature of scientific questions are more complex than the previous findings in the existing literature (e.g., McComas, 1996). Regarding phantasy-based reasoning, for example, we uncovered five sub-reasoning types. Even if some research (e.g., Karpudewan & Roth, 2018) emphasized that value-based reasoning was one of the reasons for students’ reaching a single conclusion, we encountered some other reasoning mechanisms (e.g., problematic causal reasoning, problematic induction, excessive imagination, and problematic logic) that were not available in the previous research. Perhaps because most of the NOS research covered uncontextualized interview/Vignette questions (e.g., do you think that scientific knowledge is certain?), the researchers in previous studies particularly covered, what is called, positivistic beliefs (e.g., Comte’s [1830/2015] philosophy) such as scientific knowledge is certain, theories are facts and so on (Doğan & Özcan, 2010; McComas, 1996). Because we contextualized the nature of science within socioscientific cases, we noticed that we caused some students to use some problematic reasoning types that they frequently use for meaning-making of natural events (e.g., the students’ teleological problems about ecosystems in Grotzer & Basca, 2003). Therefore, we can argue that what we found that is different from existing findings might be called ‘reasonings about the science within context’ rather than ‘reasonings about science itself’ (Kinslow et al., 2018). We believe that such contextualized cases are more important to students’ epistemic development than decontextualized versions because one of the main goals of science education is to transfer these reasonings through daily life contexts (Cian, 2020).

In the case of data-based reasoning, on the other hand, we can argue that our sub-reasoning types are the extended and gathered version of the previous findings. Sadler et al. (2004), for example, used classifications such as ‘data concerns’ (multiple-methods epistemology and multiple-data epistemology in our list) and ‘beliefs and opinions’ (multiple approaches epistemology in our list) that could easily matched with our classifications. Yenice et al. (2018) findings are also consistent with multiple-approach epistemology,

multiple methods epistemology, multivariate epistemology, and multiple-data epistemology because these researchers argued that the school students were aware of the importance of subjectivity, creativity, and imagination in science. In addition, like some students in the present study, Deve and Küçük (2016) argued that some students knew the falsifiable character of scientific knowledge. In addition, evidence-based reasonings of the school students in the research of Karpudewan and Roth (2018) also look like 'best argument epistemology' in the present study, even though some students in our research emphasized the importance of further research and evidence in order to reach the best response (rather than the right response) among the alternatives. It seems that only the 'conditional relativity' is not available in previous findings. In addition, the students exhibiting data-based reasoning in the present study also achieved certain tenets of 'consensus view' (Abd-El-Khalick, 2012; Lederman et al., 2002) such as 'creative and imaginative nature of scientific knowledge' (e.g., multiple approaches epistemology), 'theory-laded nature of scientific knowledge' (e.g., multiple approaches epistemology), 'social and cultural embeddedness of scientific knowledge' (e.g., multiple approaches epistemology), 'myth of existence of a scientific method' (e.g., multi-methods epistemology, multiple data epistemology, multivariate epistemology) and 'tentative nature of scientific knowledge' (e.g., falsification, conditional relativity and best argument epistemology). Taken together, the data-based reasoning in the present study seems to cover not only all of the previous classifications but also put forward several new ones.

Looking at the development themes, the following two conclusions may be put forward using present findings: 1) Some students, regardless of age, did not change their phantasy-based reasoning through SSI-based education. 2) SSI-based education is particularly influential in older students in terms of developing students' reasonings about response nature of scientific questions.

Regarding the first conclusion, similar to the study of Khishfe (2022), we can argue that 7 out of 15 students in 5<sup>th</sup>-grade students and 5 out of 24 8<sup>th</sup> grade students did not change their phantasy-based reasoning through SSI-based education even if their sub-reasoning types changed. This means that many school students particularly use their phantasies in their reasonings about multiple response nature of scientific questions. Once they initiate the use of these phantasies, it seems that they become resistant to, changing this mental tool even if they experience a strong intervention targeting the epistemic development. This is an alarming

result considering the importance of directing students from naïve NOS reasonings through sophisticated versions (e.g., [NGSS] Lead States, 2013).

Regarding the second conclusion, we can argue that SSI-based education, one way of developing reasonings about NOS (Sadler et al., 2004), was influential in older school students. Considering the development from phantasy-based reasoning through data-based reasoning as the positive and demanded development, we can argue that such positive development did not occur in the 5<sup>th</sup> grade students, whereas it was achieved almost one in one-third of the students in the 8<sup>th</sup> grade students. Even if this result may stem from the differences in terms of the teaching units, modules, and the teachers in the experimental classrooms, it was considered that such a result needed further discussion. Consistent with present findings, Doğan and Özcan (2010) showed that 7<sup>th</sup> grade students developed their understanding of the accuracy and uncertainty of scientific knowledge after a history-based science education. Similarly, Deve and Küçük (2016) displayed that 7<sup>th</sup> grade students could enhance their NOS understanding after a history-based science education. In addition, Karpudewan and Roth (2018) showed that 12-year-old students (who are almost at Grade 7 according to the present study's context)' decision-making modes changed from intuitive decision-making to evidence-based after SSI-based instruction. Intuitive decision-making responses in their study were similar to phantasy-based reasoning in the present study, whereas evidence-based decision-making responses were similar to data-based reasoning in the present study. However, these consistent findings may cause a misinterpretation. The present study and supporting literature show that older students present an epistemic plasticity to the epistemic development attempts. However, this does not mean that most of the younger students possess some mental barriers to developing data-based reasoning. About half of the 5<sup>th</sup> students in the present study, for example, have already used data-based reasoning before the SSI-based intervention. The possible interpretation in this context may be the fact that those in younger ages with fantasy-based reasoning seem to be more resistant to epistemic development attempts than students in older ages. At this point, Sutter's et al. (2019) findings may explain why these young students experience such resistance. He displayed that 6th-grade students with limited abstracting abilities focused particularly on concrete negative examples with limited interpretations in SSI cases, whereas those with strong abstracting abilities benefit from sound interpretations. Therefore, we may argue that some younger students who are easily emotionally aroused, perhaps because of limited abstracting abilities, benefit from phantasy-based reasoning about the multiple response nature of scientific

questions. This reasoning is resistant to the epistemic development interventions because of age-related abstraction issues.

### **Implications**

The present study may produce two implications for different stakeholders in the science education community:

#### **Science Education Researchers**

The science education researchers may benefit from the present study's classifications of reasonings about the multiple response nature of scientific questions uncovered using a sound philosophical background and the findings thoroughly uncovered via naturalistic methodologies. These relatively clear classifications may have the potential to resolve the confusion within the NOS literature by easing the classifications and to make a contribution to reaching promising purposes of NOS-based science education reforms (e.g., [NGSS] Lead States, 2013; American Association for the Advancement of Science [AAAS], 1990; [CMEC], 1997; National Research Council [NRC], 2012).

#### **Science Teachers**

To understand whether they reach the learning outcomes regarding NOS tenets, as science education researchers can do, science teachers can benefit from the present study's reasoning classifications as the rubrics. In addition, it seems that they need to be careful in designing epistemic development interventions (e.g., explicit NOS teaching, SSI-based education, history-based science education) for younger grades because the success of such interventions may be dependent on the abstraction abilities of school students.

## **Compliance with Ethical Standards**

### *Disclosure of potential conflicts of interest*

The authors declare no conflict of interests with respect to the study.

### *Funding*

The data of the project 115K492, 'Educating science teachers about teaching socioscientific issues: A professional learning community study' supported by TUBITAK, has been used in the paper.

### *Credit author statement*

Both of the authors have contributed equally to the paper. The authors have analyzed the data, developed arguments, and written the paper jointly.

### *Research involving Human Participants and/or Animals*

This study was reviewed and approved by the Ethical Committee of the Social and Humanities Research and Publication Ethics Committee at Bursa Uludağ University, Türkiye. All procedures followed national ethical guidelines, and informed consent was obtained from all participants prior to their involvement in the study.

---

## **SBK Temelli Bir Eğitim Aracılığıyla Ortaokul Öğrencilerinin Bilimsel Soruların Çok Yanıtlı Doğası Hakkındaki Muhakemelerinin Ortaya Çıkarılması**

---

### **Özet:**

Araştırmanın amacı, 'Ortaokul öğrencilerinin SBK temelli bir eğitim yoluyla bilimsel soruların çoklu yanıt niteliğine ilişkin muhakemelerinin doğası nedir' araştırma sorusuna yanıt bulmaktır. Bu akıl yürütmelerin gelişimini, bağlam temelli öğretim etkinlikleriyle (öğrencilerin açık uçlu sorgulamalar, deneyler, ahlaki tartışmalar vb.) karşılaştığı SBK temelli bir eğitim aracılığıyla ortaya çıkardık. Bu amaçla, eksik veriler ve iki farklı bilim insanının birden çok yanıtı nedeniyle yanıtlanmamış bir sosyo-bilimsel soruyu kapsayan özel olarak tasarlanmış Vignetler kullanarak 15 5. sınıf ve 24 8. sınıf öğrencisinin bilimsel soruların çoklu yanıt niteliğine ilişkin akıl yürütmelerini ortaya çıkardık. Veri analizinde, içerik analizi prosedürlerini kullanarak öğrencilerin muhakemelerini tematik olarak grupladık. Sonuçlar, öğrencilerin bilimsel soruların çoklu yanıt doğası hakkında ya fantezi temelli ya da veri temelli akıl yürütmeyi kullandıklarını gösterdi. Ayrıca öğrencilerin bu iki ana muhakeme altında çeşitli alt muhakeme türlerini (örn. sorunlu tümevarım, aşırı hayal gücü, en iyi argüman epistemolojisi, koşullu görelilik vb.) kullandıklarını fark ettik. Bu muhakeme tipleri, öğrencilerin bilimin doğası hakkındaki bakış açılarını sosyobilimsel konular bağlamında anlamada bir ölçüt olarak kullanılabilir.

*Anahtar kelimeler:* Bilimin doğası, bilimsel soruların çok yanıtlı doğası, ortaokul öğrencileri, sosyobilimsel konu temelli eğitim.

---

## References

- Abd-El-Khalick, F. (2012). Examining the sources for our understandings about science: Enduring confluences and critical issues in research on nature of science in science education. *International Journal of Science Education*, 34(3), 353-374.  
<https://doi.org/10.1080/09500693.2011.629013>
- Allchin, D. (2011). Evaluating knowledge of the nature of (whole) science. *Science Education*, 95(3), 518-542. <https://doi.org/10.1002/sce.20432>
- American Association for the Advancement of Science [AAAS]. (1990). *Science for all Americans*. Oxford University.
- Bacon, F. (2012). *Novum organum, aphorisms concerning the interpretation of nature and the kingdom of man* (S. Önal, Trans.). Say. (Original work published 1620).
- Cian, H. (2020). The influence of context: comparing high school students' socioscientific reasoning by socioscientific topic. *International Journal of Science Education*, 42(9), 1503-1521. <https://doi.org/10.1080/09500693.2020.1767316>
- Comte, A. (2015). *Positive philosophy lessons and talk on positive understanding*. (E. Ataçay, Trans.). Bilgesu. (Original work published 1830).
- Council of Ministers of Education, Canada. (1997). *Common framework of science learning outcomes, K to 12: Pan-Canadian protocol for collaboration on school curriculum*.  
<https://archive.org/details/commonframework00coun/page/n17/mode/2up>
- Creswell, J. W. (2017). *Educational research: planning, conducting, and evaluating quantitative and qualitative research*. Edam.
- Çetinkaya, E. (2019). The effects of open-thought-provoking treatment-based activities on the views of secondary school students' nature of science. *Journal of Theoretical Educational Sciences*, 12(1), 227-259. <https://doi.org/10.30831/akueg.382049>
- Deve, F., & Küçük, M. (2016). The effect of history of science-based light unit on the 7th grade students' nature of science views. *Turkish Journal of Teacher Education*, 5(1), 1-25. <https://tujted.com/makale/638>
- Doğan, N., & Özcan, M. B. (2010). The effect of the historical approach on the development of 7th grade students' views on the nature of science. *Ahi Evran University Journal of Kırşehir Education Faculty*, 11(4), 187-208.  
<https://dergipark.org.tr/en/pub/kefad/issue/59501/855322>
- Eastwood, J. L., Sadler, T. D., Zeidler, D. L., Lewis, A., Amiri, L., & Applebaum, S. (2012). Contextualizing nature of science instruction in socioscientific issues. *International*

- Journal of Science Education*, 34(15), 2289-2315.  
<https://doi.org/10.1080/09500693.2012.667582>
- Grotzer, T. A., & Basca, B. B. (2003). How does grasping the underlying causal structures of ecosystems impact students' understanding? *Journal of Biological Education*, 38(1), 16-29. <https://doi.org/10.1080/00219266.2003.9655891>
- Herman, B.C., Poor, S.V., Oertli, R.T., & Schulte, K. (2023). Promoting young learners' NOS views through place-based SSI instruction. *Science & Education*, 32(4), 947-992.  
<https://doi.org/10.1007/s11191-022-00353-z>
- Irzik, G., & Nola, R. (2011). A family resemblance approach to the nature of science for science education. *Science & Education*, 20, 591-607. <https://doi.org/10.1007/s11191-010-9293-4>
- Johnston, A. T., & Southerland, S. A. (2001). The multiple meanings of tentative science. *Proceedings of the Sixth International History, Philosophy and Science Teaching Conference, USA*, 66,1-15.
- Karisan, D., & Zeidler, D. L. (2017). Contextualization of nature of science within the socioscientific issues framework: A review of research. *International Journal of Education in Mathematics, Science and Technology*, 5(2), 139-152.  
<https://files.eric.ed.gov/fulltext/EJ1124953.pdf>
- Karpudewan, M., & Roth, W. M. (2018). Changes in primary students' informal reasoning during an environment-related curriculum on socio-scientific issues. *International Journal of Science and Mathematics Education*, 16(3), 401-419.  
<https://doi.org/10.1007/s10763-016-9787-x>
- Khishfe, R. (2022). Nature of science and argumentation instruction in socioscientific and scientific contexts. *International Journal of Science Education*, 44(4), 647-673.  
<https://doi.org/10.1080/09500693.2022.2050488>
- Kinslow, A. T., Sadler, T. D., & Nguyen, H. T. (2018). Socio-scientific reasoning and environmental literacy in a field-based ecology class. *Environmental Education Research*, 25(3), 388-410. <https://doi.org/10.1080/13504622.2018.1442418>
- Kuhn, T. S. (2017). *The structure of scientific revolutions*. (N. Kuyaş, Trans.). Kırmızı. (Original work published 1962).
- Lederman, N. G., Abd-El-Khalick, F., Bell, R. L., & Schwartz, R. S. (2002). Views of nature of science questionnaire: Toward valid and meaningful assessment of learners' conceptions of nature of science. *Journal of Research in Science Teaching*, 39(6), 497-521. <https://doi.org/10.1002/tea.10034>

- Lincoln, Y. G., & Guba, E. (1985). *Naturalistic Inquiry*. Sage.
- McComas, W. F. (1996). Ten myths of science: Reexamining what we think we know about the nature of science. *School Science and Mathematics*, 96(1), 10-16. <https://doi.org/10.1111/j.1949-8594.1996.tb10205.x>
- National Research Council [NRC]. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. National Academies.
- NGSS Lead States. (2013). *Next generation science standards: For states, by states*. National Academies.
- Popper, K. R. (2017). *The logic of scientific research*. (İ. Aka & İ. Turan, Trans.). Yapı Kredi. (Original work published in 1934).
- Ravetz, J. (2012). The significance of the Hamburg workshop: Post-normal science and the maturing of science. *Nature and Culture*, 7(2), 133-150. <https://doi.org/10.3167/nc.2012.070202>
- Rudge, D. W., Cassidy, D. P., Fulford, J. M., & Howe, E. M. (2014). Changes observed in views of nature of science during a historically based unit. *Science & Education*, 23(9), 1879-1909. <https://doi.org/10.1007/s11191-012-9572-3>
- Sadler, T. D., Chambers, F. W., & Zeidler, D. L. (2004) Student conceptualizations of the nature of science in response to a socioscientific issue. *International Journal of Science Education*, 26(4), 387-409. <https://doi.org/10.1080/0950069032000119456>
- Sanitt, N. (1996). *Science as a questioning process*. CRC.
- Solomon, J., Duveen, J., Scot, L., & McCarthy, S. (1992). Teaching about the nature of science through history: Action research in the classroom. *Journal of Research in Science Teaching*, 29(4), 409-421. <https://doi.org/10.1002/tea.3660290408>
- Sutter, A. M., Dauer, J. M., Kreuziger, T., Schubert, J., & Forbes, C. T. (2019). Sixth grade students' problematization of and decision-making about a wind energy socio-scientific issue. *International Research in Geographical and Environmental Education*, 28(3), 242-256. <https://doi.org/10.1080/10382046.2019.1613586>
- Yenice, N., Alpak Tunç, G., & Yavaşoğlu, N. (2018). Examining the scientific epistemological beliefs of secondary school students. *The Journal of Mehmet Akif Ersoy University Faculty of Education*, 45, 132-152. <https://doi.org/10.21764/mauefd.334536>
- Zeidler, D. L., & Kahn, S. (2014). *It's debatable! Using socioscientific issues to develop science literacy*. NSTA.

## **Appendix 1. 5<sup>th</sup> Grade Vignette**

### **SHOULD THE DETERGENT FACTORY BE CLOSED?**

About five years ago, a detergent factory was established about 12 km from Bozkır village. 35 employees work in this factory. Twenty-five of these workers are peasants living in the village of Bozkır.

There has been a problem in the village for about two months. Children experience severe diarrhea and intestinal problems, and peasants are constantly coming to the Family Health Center. Regarding the reason for this situation, the district governor of the village to which the village is connected, the village headman, one of the villagers working at the factory, a biologist working on environmental pollution in the region, and a biologist working at the Family Health Center came together. Talks between them are given below:

**District Governor:** Yes, friends. We have such a problem. Although there has been no problem since I started working five years ago, there have been patients who have applied to the Family Health Center for two months. Two or three children a day come with severe diarrhea. What do you think?

**Headman:** I think all of these came from the factory. Strange odors come when we smell our tap water. The color of the water is not the same as before. We are obliged to drink these waters because the fountains are also dry. Chemicals from the factory may have somehow been transported here.

**The peasants working at the factory:** I have been working at the factory for five years. Our factory is very serious about cleaning and hygiene. They want us to constantly wash our hands and wear plastic glasses and mouthpieces. Our manager at the factory is also very knowledgeable. I do not think that such a factory will harm the environment.

**A biologist working on environmental pollution:** I have been working in this region for about ten years. Ten years ago, I took samples from 130 trees in the region. The proportion of metals such as lead and mercury was negligible in these trees. However, in the samples I took a month ago, the lead and mercury rates in all of the trees increased three times. Although I did not do such a study with people, I think there is a chemical poisoning in the area.

**A biologist working at the Family Health Center:** In our tests with the blood of children coming to our center, we observed an increase in the cells that fight microbes. We also found high levels of bacteria in both blood and stool samples. We suspect an epidemic that affects the entire region. Unfortunately, we do not have tests to analyze metals such as lead and mercury in human blood. We would like to look at them too.

**Question:** We see that biologists have different views about the cause of diseases in children. In your opinion, wouldn't a question have a single response in science? Could you please write your answer in the blank below?

## **Appendix 2: 8th Grade Vignette**

### **SHOULD AGRICULTURE BE DONE AROUND THE LAKE?**

Mahmutlar Village was established around a lake. People living in this village earn their lives by both wheat farming and fishing. There is a living ecosystem in the lake. There are mosses at the bottom of the lake and herbivorous Carps and carnivorous Crane fishes in the lake. In addition, Heron Eagle, which is about to become extinct, also nest in the region. It is seen that these eagles sometimes hunt squirrels eating walnuts.

The villagers have recently observed that many Heron Eagles have died and reported this to the district governor's office. The District Governorate brought together residents of the village and scientists working in the region.

**Governor Mehmet:** Yes, friends. There are reports that a large number of Heron Eagle died in Mahmutlar Village. What do you think about the reason for this situation?

**Mrs. Ayşe (villager):** I think a disease has killed them. When we looked at these eagles, we saw that they were all very weak. They probably got sick and died because they could not hunt anything.

**Biology Professor Nergiz:** We looked at the blood of eagles that are about to die. We found twice as many chemicals in their blood as normal. These substances are also found in pesticides used by peasants. Field pesticides were mixed with groundwater, and these waters came to the lake through streams. Somehow, these chemicals were transported to the Heron Eagles with the food chain.

**Biology Professor Arif:** I do not think it is related to agriculture. The ground of this lake is tough enough to prevent water from getting outside. Think like a dish. So the main water source of this lake is just rain.

**The headman Selim:** We have been farming around the lake for years. Our main source of livelihood. All families eat what we produce in these fields. Nothing happened to anyone for years. I do not think it is a problem with agriculture.

**Question:** We see that biology professors have different views about the effects of farming around the lake. In your opinion, wouldn't a question have a single answer in science? Could you please write your answer in the blank below?