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ORIGINAL ARTICLE

Informal Reasoning Patterns and Socioscientific Reasoning of Middle School Students on Local and General Socioscientific Issues

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ABSTRACT

The purpose of this study was to examine middle school students' informal reasoning patterns and socioscientific reasoning about local and general socioscientific issues (SSI). The study was conducted with 59 7th-grade students using a case study, a qualitative research design. Data collection included activity sheets completed by students based on prepared scenarios and a SSI survey. Data were analyzed using descriptive analysis. It was found that middle school students frequently used the rational reasoning pattern, one of the informal reasoning patterns, in local and general SSIs. Participants grasped the complexity of the subject better and produced solutions in the complexity aspect of socioscientific reasoning in local SSIs compared to general SSIs. Beyond the local-general distinction, the findings revealed that students' reasoning patterns were also shaped by their prior experiences, the emotional relevance of the topic, and the degree to which SSIs directly affect daily life. To develop students' socioscientific reasoning and informal reasoning, it is recommended to include scenarios for local SSIs in textbooks and curricula, and to deliberately integrate issues with strong experiential, emotional, and everyday-life connections to foster the balanced use of rational, intuitive, and emotional reasoning.

KEY WORDS: General socioscientific issues, informal reasoning, local socioscientific issues, socioscientific issues

INTRODUCTION

Scientific and controversial issues that concern society are referred to as "socioscientific issues." Socioscientific issues (SSIs) are controversial phenomena based on scientific concepts and problems that are complex, open-ended, and have no definitive answer (Sadler, 2004; Topçu, 2017). They often involve ethical, moral, and legal dilemmas (Dawson and Venville, 2009; Kolstø, 2001; Öztürk and Turgut, 2017; Sadler, 2004).

Since SSIs are issues that directly affect society, each individual should be able to weigh the risks and benefits, ask questions about the topic, evaluate the results, and make decisions using their prior knowledge (Sadler and Zeidler, 2005a; Dawson and Venville, 2009). When SSIs are supported by a curriculum, it can enable students to learn scientific topics and improve their reasoning skills (Sadler and Zeidler, 2005b; Akbaş and Çetin, 2018). SSIs can be general or local in context (Çapkınoğlu et al., 2020; Durak and Topçu, 2023; Wiyarsi et al., 2024). Local SSIs are controversial issues that emerge within specific regions and have unique characteristics influenced by regional conditions and culture (İllahi et al., 2024). For example, Indonesia has a volcanic geography, so discussing the advantages and disadvantages of the presence of volcanoes is important for the people of that region, whereas in a country, such as Turkey, which does not have active volcanoes, such an SSI will not receive the same level of attention (Wiyarsi et al., 2024). For this reason, incorporating both general and local SSIs into science education creates a chance for people to understand their realities and develop their worldviews within their own contexts. Research indicates that culture and common habits affect individuals' objectivity and open-mindedness (Wiyarsi et al., 2021). Science is also shaped by cultural and contextual factors. For this reason, investigating how cultural values and social beliefs influence the understanding of science (Evagorou et al., 2012; Wiyarsi et al., 2021) has been the starting point of this study. In the literature, studies have examined both general (Sadler and Zeidler, 2005b; Yolaçtı Kızılkaya and Öztürk, 2022) or local (Evagorou et al., 2012; Kolstø, 2006; Patronis et al., 1999) SSIs. However, based on the fact that cultural values, common habits, and beliefs can carry the reasoning about an SSI to different aspects and shape ideas, in this study, unlike the literature, middle school students' informal reasoning and socioscientific reasoning will be examined comparatively in the context of both general and local SSIs. The study will contribute to the development of a more holistic approach to the teaching of SSIs by revealing how students shape the same types of reasoning in different SSI contexts. This research

1 This research constitutes part of a master's thesis conducted by the first author under the supervision of the second author

contributes to a deeper understanding of the role of cultural and local factors in science education by highlighting the significance of context in teaching SSIs.

The aim of the study is to examine middle school students' informal and socioscientific reasoning regarding local and general SSIs.

1. What are the informal reasoning patterns of middle school students regarding local (nuclear power plant and fishing activities in the Black Sea) and general (cryobiology and the use of plastic) SSIs?
2. How do middle school students' socioscientific reasoning patterns differ in relation to local (nuclear power plant and fishing activities in the Black Sea) and general (cryobiology and the use of plastics) SSIs?

Informal reasoning refers to reasoning that occurs outside the contexts of mathematics and symbolic logic (Zohar and Nemet, 2002). When reasoning about SSIs, students need to be able to reason from multiple perspectives (Perkins, 1985). Informal reasoning requires the ability to consider the pros and cons of issues, to think about what the benefits and harms might be, and to make connections between cause and effect (Zohar and Nemet, 2002). Informal reasoning becomes particularly important in situations that are open-ended, controversial, Complex, require negotiation, involve argument construction, and claim development, and where information is not easily accessible (Means and Voss, 1996). Using informal reasoning, which draws upon multiple sources of information and allows for a range of possible outcomes to emerge, is considered an appropriate approach when reasoning about SSIs (Chang and Chiu, 2008). Researchers categorize informal reasoning as social, economic, ecological, and practical (Patronis et al., 1999); rational, intuitive, and emotional (Sadler and Zeidler, 2005a); or social, economic, ecological, science, and technology (Wu and Tsai, 2007).

In this study, informal reasoning was examined within the framework of the patterns identified by Sadler and Zeidler (2005a). The rational informal reasoning pattern is based on causal calculations and evaluations, such as utilitarianism and cost-benefit analysis, being emphasized in this pattern (Sadler and Zeidler, 2005a). Within the rational informal reasoning pattern, individuals formulate and justify their ideas based on reason and logic. The intuitive informal reasoning pattern refers to positive or negative reactions to the subject matter that arise from sudden cognitive impulses without explicit explanation (Sadler and Zeidler, 2005a; Özden, 2020). The emotional informal reasoning pattern involves emotional states, such as empathy and sympathy, as well as identification with individuals who will be affected by the decision (Öztürk and Bozkurt Altan, 2021). This pattern represents a reasoning situation in which emotions are dominant but not independent of logic, the well-being of others is prioritized, and the human element is central (Sadler and Zeidler, 2005a).

Socioscientific reasoning includes citizenship education as well as science and refers to the elements individuals should use while reasoning, which are inherent in SSIs (Topçu, 2017). Socioscientific reasoning has a four-dimensional structure (Sadler et al., 2007; Karahan and Roehring, 2016; Romine et al., 2017). These aspects include understanding the complexity inherent in socioscientific reasoning (complexity), addressing different perspectives on the topic under discussion (perspectives), recognizing its inquiry-based nature (inquiry), and approaching biased information with skepticism (skepticism). The complexity aspect refers to issues that are complex, contentious, dilemma-based, controversial, open to discussion, and without a single correct solution (Sadler et al., 2007). As a result of the fact that science is a human product and directly connected to society in which it is born (Sadler and Zeidler, 2004), the discussion, discourse-based activities, dialogue, and the socialized learning that it brings with it enable students to realize the complexity aspect of the subject. In this way, it is aimed to enable individuals to go beyond a simple cause-and-effect relationship of events (Topçu, 2017). The perspective aspect contributes to the controversial nature of SSIs. Individuals differ in their cognitive approaches, prior knowledge, value judgments, prejudices, and guiding principles (Sadler et al., 2007). The perspective aspect of SSIs requires openness to opposing views and understanding the mindsets of other individuals (Romine et al., 2017). In this way, students gain awareness that there may be opinions different from their own, empathize, socialize, and develop their scientific thinking skills. The inquiry aspect of socioscientific reasoning is related to the incompletely structured and problematic nature of SSIs (Sadler et al., 2007). Since SSIs, which are at the intersection of social and scientific fields, include human behavior, psychology, economic and social norms, they require multiple modes of thinking. These processes develop in parallel with individuals' inquiry skills (Sadler et al., 2007). Skepticism is a mindset necessary for conducting research and solving scientific problems (National Research Council [NRC], 2000). Individuals' self-interests, prejudices, and experiences related to SSIs affect the ideas and evidence put forward. Students need to take all these factors into account when reasoning about such issues (Sadler et al., 2007).

An advanced level of socioscientific reasoning requires recognizing the complexity inherent in SSIs, developing diverse perspectives by examining problems from multiple sources, and critically evaluating biased information with awareness that it is subject to inquiry (Topçu, 2017). Individuals may be proficient in analyzing accessible information by using cognitive skills, such as skepticism, critical thinking, and inquiry. However, in addition to these, it is necessary to develop decision-making skills through socioscientific reasoning to structure SSIs effectively in the mind (Zeidler et al., 2005).

METHODOLOGY

Research Model

The study was conducted within the framework of qualitative research methodology. Qualitative studies require understanding the "*why*" and "*how*" of events, phenomena or behaviors

based on individuals' own understanding, comprehension, and perception (Seggie and Bayyurt, 2017; Baltacı, 2019). In this study, participants' informal reasoning patterns and socioscientific reasoning were examined in depth based on the content of SSI (local or general). A holistic multiple-case design, one of the case study approaches, was employed in this study. According to this design, there is more than one case that can be perceived as holistic on its own. Different cases can be compared with one another, yet each can also be considered holistically on their own (Yin, 1981). Within the scope of this study, local and general SSI were accepted as a situation. First, the data for each SSI were analyzed in depth, and then the relationships and differences between the situations were identified. The study sought to answer the "why" and "how" questions regarding both the process and the outcome.

Study Group

He participants were 13–14-year-old middle school students from the district center and remote villages, representing diverse socioeconomic and cultural backgrounds and varying levels of achievement. There were 59 volunteer participants in the study group, 30 females and 29 males. The study was conducted with 7th-grade students in 3 different sections (Section 1: 9 girls, 12 boys; Section 2: 11 girls, 8 boys; Section 3: 10 girls, 9 boys).

Data Collection Tools

Data were collected through SSI scenarios (activity sheets) prepared by the researcher, a decision-making opinion form, and observation.

SSI scenarios (activity sheets)

Contextualized scenarios are used in teaching SSI (Zeidler and Nichols, 2009). Within the scope of the study, SSI scenarios were prepared in the context of 2 local and 2 general issues. While planning SSI scenarios, some criteria were determined based on the literature: Having a multidimensional structure that includes science, ethics, economy, environment, politics, and sociology; having a structure that reflects dual and different views on the subject; containing scientific sources that approach the subject from different perspectives; local SSIs include examples drawn from news in the local region.

The first of the local SSIs was the scenario on the establishment of a nuclear power plant in the city. The process of establishing a nuclear power plant in the city is ongoing. The issue is a matter of public concern due to its environmental aspects, such as the risk of a nuclear power plant explosion and the environmental damage of its wastes. On the other hand, proponents support the establishment of a nuclear power plant due to its political and economic benefits. The scenario presents evidence of different perspectives in this framework. There are also perspectives on the issue from science, ethics, economics, environment, politics, and sociology. The second scenario is about cryobiology, a general SSI. Although cryobiology is seen as an advantage for organ transplantation and endangered species, it is a controversial SSI due to the difficulties in its implementation and ethical dilemmas. The third SSI addressed fishing activities, which are discussed locally. The fishing depth of 18 or 24 m is a controversial issue for the people living in this region. While 18 m poses dangers in terms of damage to fish nests and the decrease in fish species because of the deterioration of the ecological balance in the Black Sea, 24 m is seen as an economic loss for people who make a living from fishing, and is a local practice that is opposed. The fourth SSI is the use of plastic, which is a general SSI. While the use of plastics is viewed negatively in terms of its effects on environmental pollution and the harm it causes to living things through the food chain, it is also considered as a general SSI that causes the formation of opposing views due to its widespread use.

The activity sheets were prepared within the framework of the above-mentioned SSIs. In the activity sheets, there is a section where the students use their existing knowledge to express what they think individually about the situation presented in the scenario and express their decisions and justifications after the in-class discussion. The written opinions of the students were taken as the data source of the study.

Decision-making questionnaire

A form consisting of 5 open-ended questions about each SSI scenario was prepared by the researchers and used as a data collection tool. The form was prepared to determine the students' evaluation of SSI from different perspectives, their characteristics of inquiry and skepticism, and to investigate students' informal reasoning and socioscientific reasoning. For this reason, questions were prepared within the scope of informal reasoning components defined by Sadler and Zeidler (2005a) and socioscientific reasoning components defined by Sadler et al. (2007). In this context, for example, in the form related to the SSI for the establishment of a nuclear power plant, questions, such as "*Thoughts about the nuclear power plant that is planned to be established in the city where you live, the factors that influenced your decision, evaluations of the issue from different perspectives (positive and negative), which circles/people are concerned with the decision about the specified SSI, how the perspectives of different circles may be, whether they need more information on the subject, if so, what these are, what kind of issues they are inquiring about, whether there are issues that they are skeptical about the information given in the scenario or the information they have obtained through their research, and if so, what these are and why they are skeptical".* The opinions of two experts were sought on the appropriateness of each form for the scope. Experts suggested that the concepts of questioning and skepticism should be expressed more directly. In this context, necessary arrangements were made. Then, the questions were applied to 6 students outside the study group for comprehensibility. The final version was produced by making corrections based on the feedback received from the students. Forms were applied after the implementation of each scenario.

Observation

One of the researchers was involved in the process as a participant observer. In the case of participant observer, the

researcher remains in the situation for a limited period. She informs the participants and obtains their consent to observe (Christensen et al., 2015). The students' emotions transformed into actions, especially during the discussion process, and their gestures, facial expressions, and body language were also considered important for the research. For this reason, observations were also included in the findings of the study to support the data of the research and to evaluate the data that could not be obtained in writing. In terms of data triangulation, the researcher's own observations were also characterized as descriptive and analyzed under a separate heading in the findings section. The observations were based on the questionnaire for the decision-making process. Audio recordings were made to ensure the permanence of the expressions regarding the observations, a more regular collection of data, and re-checkability. The students were informed that voice recordings would be made, and voice recordings were preferred instead of video recordings to avoid distraction. The audio recordings were not analyzed separately. They were used to aid the analysis of observation notes and to recall the process accurately.

Data Collection Process

The data collection process was conducted for 8 weeks and 4 lessons (45 min) each week, totaling 32 lessons. The students were informed one week in advance about the SSI that would be presented in the lesson and were asked to conduct research on the topic. Research practice was carried out in a 40-min computer laboratory session using an SSI not included in the study (the consumption of chicken meat) as an example. They were instructed to conduct their research by taking into account both the positive and negative aspects of the topic and by reflecting at least 2 positive and 2 negative perspectives and noting the sources they consulted to intuit the dichotomous structures of the SSI. For example, in the scenario on the use of plastic, topics, such as the importance of plastic in our daily lives, its benefits for the economy, the prevalence of its usage areas, its effects on pollution, its effects on living things through the food chain, recycling, and alternative ways to reduce its damages were investigated. In the scenarios prepared by the researchers, the effects of plastic use on the world were addressed globally in terms of benefits and harms and evaluated as a general SSI.

When the lesson process started, they were first asked to read and analyze the SSI scenario presented to them, and explanations were given at points that were not understood. After the scenarios were analyzed, the research conducted by the students was questioned. In the continuation of the process, class discussion techniques were used, and students were allowed to express their ideas freely and without hesitation. During the discussions, the researcher acted as a participant observer. During the discussion, as many students as possible were given the right to speak and an environment was created in which students could express themselves comfortably. Students were able to do research on the internet to access the information they needed during the discussion. Audio recordings were taken during the lesson. When the discussion was completed, the students first wrote their decisions and justifications in the relevant sections of the activity sheets. A questionnaire about the decision-making process was presented, explanations about the questionnaire were made, and 40 min were given for them to fill in the forms individually. For 4 different scenarios, the same process was repeated.

In the 1st and 2nd weeks of the study, nuclear power plants, a local SSI, in the 3rd and 4th weeks, cryobiology, a general SSI, in the 5th and 6th weeks, fisheries, also a local SSI, and in the 7th and 8th weeks, plastic use SSI, a general issue, were included.

Data Analysis

The data were analyzed with a descriptive analysis technique. Within the scope of the research, descriptive analysis was used to examine and analyze the views expressed in the questionnaires on the decision-making process and the SSI scenarios, and findings were generated by direct quotations from the participants of the study.

To determine the informal reasoning modes and socioscientific reasoning aspects of the students, the questionnaire and activity sheets related to the decision-making process were analyzed together. In this context, students' answers in the scenario and form were analyzed independently by both researchers according to pre-determined codes. In cases where the researchers could not reach consensus, the opinions of two science education experts with experience in SSI studies were consulted.

Analysis of informal reasoning modes

In determining the informal reasoning modes of the students, the classification of rational, emotional, and intuitive informal reasoning patterns, determined by Sadler and Zeidler (2005a), presented in Figure 1, was taken as a basis.

According to Figure 1, individuals can make decisions using either a single reasoning pattern or multiple patterns

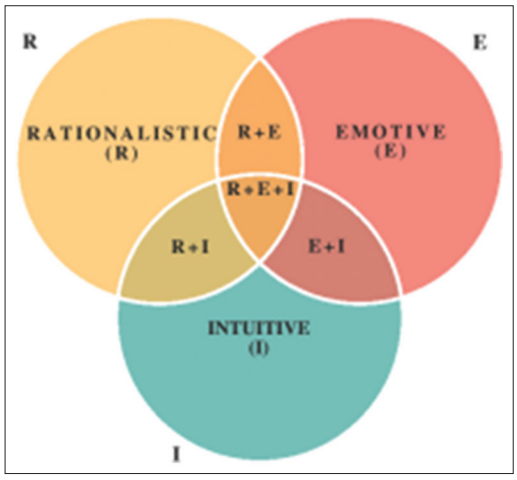

Figure 1: Informal reasoning patterns. R + E = Rationalistic + Emotive; I + E = Intuitive + Emotive; R + I = Rationalistic + Intuitive; R + E + I = Rationalistic + Emotive + Intuitive

simultaneously. The findings indicated that students used the rational reasoning pattern when making cost-benefit analyses or logic-based calculations; the intuitive reasoning pattern when responding with sudden impulses or positive and negative reactions; and the emotional reasoning pattern when focusing on emotional states, such as empathy, sympathy, and the human element (Sadler and Zeidler, 2005a). In addition, students who used two or more of these patterns together were categorized separately. To ensure the clarity of the descriptive analysis, sample statements and the corresponding informal reasoning modes are presented in Table 1.

Socioscientific reasoning analysis

To assess the aspects of socioscientific reasoning in individuals, the "*Rubric for Assessing Aspects of Socioscientific Reasoning*" proposed by Sadler et al. (2007) was used. The rubric is given in Table 2.

Examples of student statements as a result of the evaluation according to the rubric are presented in Table 3.

In Table 3, examples of the analysis of socioscientific reasoning in Sadler et al. (2007) are presented. There are no sample data at the aspect levels left blank in Table 3.

Validity, Reliability, and Ethics

To ensure the internal validity of the study, attention was given to long-term interaction, triangulation, and expert review. The study was conducted over an 8-week period to ensure long-term interaction with the participants and to align with the research content. The consistency of the data obtained during the study was carefully considered. Conceptual patterns, connections, and relationships emerging from the results were continuously examined, and their validity was questioned.

Within the scope of this study, middle school students' informal reasoning and socioscientific reasoning regarding SSIs were described in detail to ensure transferability. Direct quotations were used to enable readers to visualize the research process as clearly as possible. For internal validity, both the SSI scenarios and the SSI Questionnaire were employed to ensure diversification of data sources. Expert review was also used to strengthen internal validity. The data were analyzed with the support of an expert experienced in SSI research, through interviews conducted at certain intervals. The process was refined based on feedback received from the expert.

Similar procedures were followed in preparing all SSI scenarios, creating and implementing questionnaires, conducting studies

Table 1: Examples for analyzing informal modes of reasoning

Example student expression	Informal reasoning mode
"Let it be established. It will positively affect Turkey economically and I think we can overtake some countries by developing. If it is established, it will negatively affect the environment because there may be explosions and it may harm living things. If it is established, it will positively affect the economy. It will affect many people in the place where it is established, and it will affect animals in the sea."	Rationalist: Reflected a multidimensional perspective by analyzing the issue from a cost-benefit analysis.
"I don't want it to be built. I am afraid that the nuclear power plant will explode. If the nuclear power plant explodes, animals may be harmed."	Emotive: By indicating the emotional state, it was tried to predict what might happen in case of an explosion.
"Sinop needs an energy source, and it is a very good thing that it does not emit air pollution. Let the nuclear power plant be built, but where people do not live, where there is no one, only workers can go there. If it doesn't explode, it has no effect on the environment (in a bad sense). In a good sense, we will have a better energy source. It is not bad economically either. If it explodes, it's bad for health, but workers should do their best to prevent it from exploding."	Intuitive: Thinking in one direction, making decisions impulsively. He/she tries to generate ideas to prove his/her present decision by rationalizing it.

Table 2: Rubric for the complexity, perspectives, inquiry, and skepticism aspects of socioscientific reasoning (Sadler et al., 2007, s.380, 382)

Aspects	Levels			
	1	2	3	4
Complexity	Offers a very simplistic or illogical solution without considering multiple factors.	Considers pros and cons but ultimately frames the issue as being relatively simple with a single solution.	Construes the issue as relatively complex primarily because of a lack of information. Potential solution tends to be tentative or inquiry-based.	Perceives the general complexity of the issue based on different stakeholders, interests, and opinions. Potential solutions are tentative or inquiry-based.
Perspectives	Fails to carefully examine the issue	Assesses the issue from a single perspective.	Can examine a unique perspective when asked to do so.	Assesses the issue from multiple perspectives.
Inquiry	Fails to recognise the need for inquiry	Presents vague suggestions for inquiry	Suggests a plan for inquiry focused on the collection of scientific or social data	Suggests a plan for inquiry focused on the collection of scientific and social data.
Skepticism	Denies differences among stakeholder positions.	Ascribes differences in stakeholder positions to differences in information.	Ascribes differences in stakeholder positions to a desire to avoid blame.	Recognizes conflicting interests and purposes among various stakeholders

Table 3. Socioscientific reasoning analysis examples

Aspects	Levels	Example student expression
Complexity	1	*In my opinion, plastic should not be used, but it should be used without harming the environment, that is, it should be used without throwing it into the seas, but it should not be used by throwing it into the seas, if we throw it into the seas, fish, etc., animals may die. So let's not harm the environment and nature. I think if they throw plastic products into the seas, the fish may die and the turtles may mistake them for food and eat them, so economically we should not throw plastic products anywhere in the seas, in nature. Socially, we should not throw garbage on the ground. It can harm nature and other objects. (S7)*
	2	*It should be 24 m because there are eggs on the shores, and they can be damaged. Furthermore, they should make the nets in such a way that eggs do not enter the nets, then only the fish will enter, so the eggs will not be damaged, and they should take it because it is a source of food for people. People pollute the seas and the waste from the industries flows into the seas, lakes and rivers and the fish are decreasing because people act unconsciously. Fishermen make profit economically and because it is a source of food for people. (S15)*
	3	*I think cryobiology can be useful both scientifically and economically. Benefits: In organ transplantation, by freezing the organs, it will be easier for doctors to transplant the organs to the patient. We can advance scientifically; I think it would be very good for space travel. My decision is ethical; it depends on people's decision. Some people think in terms of religion and some people don't mix religion with science. If it works socially, people might have a chance to see a loved once again, but that person is going to die anyway, but if it works when it is frozen and wakes up, it can be very useful for people, if it is frozen and wakes up dead, there is nothing to lose. If it's frozen and wakes up healthy, it's good for us and bad for other countries. Because we advance in science. However, freezing the person will advance time. Technology, their families, environment, etc. Will they be able to get used to it when they wake up? Like this... (S49)*
	4	*I don't want it to be built because it leads to air pollution and water pollution. Living things can be affected by this situation and lose their lives. We will have economic problems. Economically, we don't need to go abroad, so we don't owe money. Environmentally, radiation is emitted from power plants and gets into the soil. This affects the food we eat and can disrupt our health, and the fumes from the factory cause air pollution. (S16)*
Perspectives	1	*I think plastic should not be used a lot, and if it is used, it is better not to throw it on the ground, in the sea, in the environment, because it can cause a lot of damage to the environment, I think it should not be used because plastic products should not be thrown into the seas, etc., otherwise they can damage everywhere. (S7)*
	2	*In my opinion, it would be good for fishermen because they would not have any difficulty because it is right in the middle, I think when it is in the middle, the fish will come just right, I think it will not be bad for anyone, I think if it is 24, it will be a bad situation for fishermen because they catch very little fish. (T34)*
	3	*If it happens in a healthy way when it is frozen and awakened, it will be good for us and bad for other countries. Because we advance in science. However, when you freeze the person, time will progress. Will they be able to get used to technology, their families, their environment, etc., when they wake up? (S49)*
	4	*For some people, it may be logical because things, such as coal and oil can harm the environment and the air. However, the destruction of a nuclear power plant as a result of an accident would cause more damage to nature, the environment, and living things. (S6)*
Inquiry	1	-
	2	*Where and how many fish are caught can affect my decision (S28).*
	3	*How can we protect the environment from this plastic? Can a device be installed in the seas for turtles and fish? Are there any dangers of unemployment for those working in the plastics industry? These can be researched on the general network (S21).*
	4	-
Skepticism	1	-
	2	*The explosion of the nuclear power plant made me doubt, but maybe it could cause me to die or become disabled (S52).*
	3	*It upset me that they experimented on animals, and it made me suspicious that nothing was certain there (S50).*
	4	-

with students, and managing classroom interactions. To ensure objectivity, the relationships between the recorded data and the results were also reviewed by an expert.

Ethics committee approval was obtained, and participants were informed about the study before the data collection process. Participants' voluntariness was confirmed, and all stated their willingness to participate by submitting consent forms to the researchers. Parental consent forms were also obtained. Two science education experts also reviewed the research process. Students' personal information was kept confidential, and their names were not included in any part of the research. The researcher adhered to ethical principles throughout the process and conducted the study within the framework of accuracy and integrity.

Findings

Findings on secondary school students' informal reasoning patterns

In this study, the patterns used by middle school students in their reasoning about SSI were analyzed according to the reasoning patterns identified by Sadler and Zeidler (2005a) and presented in Figure 2.

When the students' reasoning patterns for the decision-making process presented in Figure 2 are analyzed separately, it is seen that more intuitive (f = 24), rational (f = 15) and rational-emotional (f = 12), and less emotional (f = 4) and rational-intuitive (f = 4) patterns are used for the nuclear power plant local SSI. Informal reasoning patterns for fisheries local SSI are mostly rational (f = 27), less rational-emotional

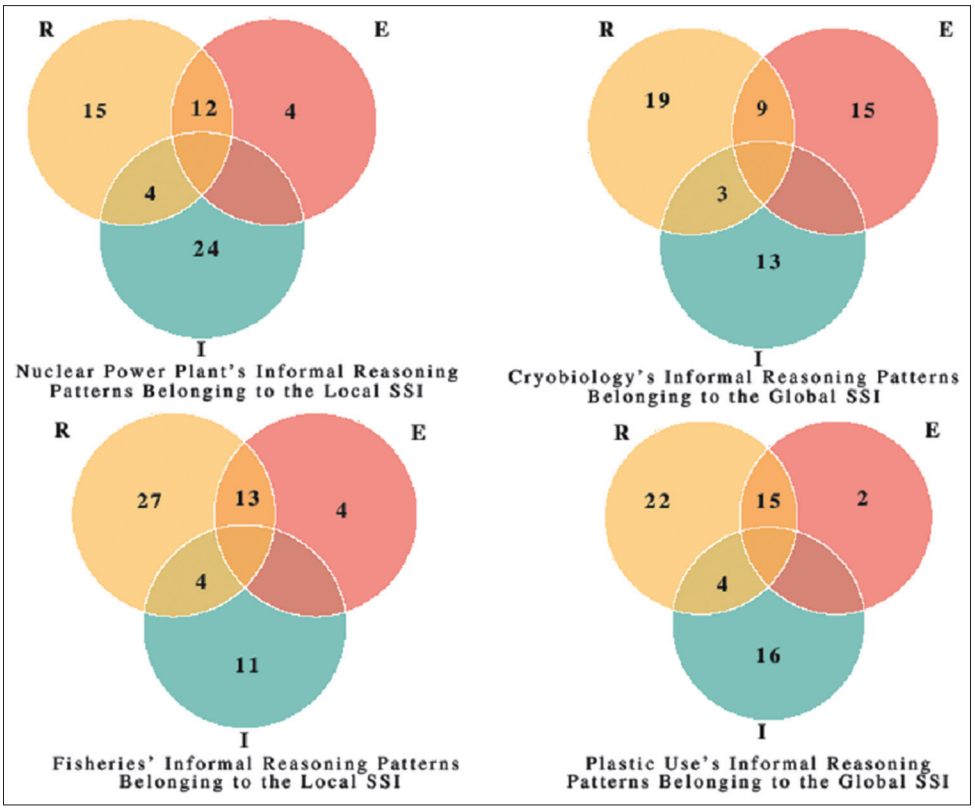

Figure 2: Finding scheme for informal reasoning patterns for local and general socioscientific issues

(f = 13) and intuitive (f = 11), and least emotional (f = 4) and rational-intuitive (f = 4). In the general SSI for cryobiology, rational (f = 19), emotional (f = 15), intuitive (f = 13), and less rational-emotional (f = 9) and very few rational-intuitive (f = 3) patterns were found. Finally, rational (f = 22), intuitive (f = 16) and rational-emotional (f = 15), and less frequently rational-intuitive (f = 4) and emotional (f = 2) patterns were observed in the general SSI of plastic use. Emotional-intuitive and rational-emotional-intuitive patterns were not encountered in any of the SSIs.

Examples of students' informal reasoning patterns for the SSI of nuclear power plants are presented below.

Emotional reasoning pattern on SSI of nuclear power plants:

> "*I don't want it to be established. I am afraid that the nuclear power plant will explode. If the nuclear power plant explodes, animals may be harmed.*" S3

Rational and intuitive reasoning patterns together on the SSI of nuclear power plants:

> "*I think it should be built. With a good worker and good security, we can be protected from explosion and thanks to this, the economy will increase and the importance of both our province Sinop and Turkey will increase. It affects the environment badly because radioactive things stay in nature for 100 years. It affects the economy well because it increases energy and our economy will increase thanks to this.*" S51

Examples of students' informal reasoning patterns for the SSI of cryobiology are presented below.

Emotional reasoning pattern on the SSI of cryobiology:

> "*It is not a right decision to freeze people. Because maybe freezing cannot be realized in humans. Therefore, I think people's lives may be in danger. For example, this freezing took place, and they are taking volunteers to test it. What if the test did not take place, that person's life could be in danger.*" S18

Examples of students' informal reasoning patterns for the fishing SSI are presented below.

Emotional reasoning pattern on the SSI of fishing:

> "*Let it be 24 meters because 18 meters, of course, even if there are no eggs, a few eggs come, and the fish are harmed. If there are no fish, people cannot feed, and the fish will become extinct, and no one can eat them. As for the economy, since there is no production, there is no economy.*" S19

Intuitive reasoning pattern on the SSI of fishing:

> "*Fishing in the Black Sea is just right, neither too much nor too little, it is enough for everyone. 18 meters is economically sufficient, fishermen are at a slight loss, but it is enough. Socially, many people need vitamins. It affects people positively as an environment. If we look at 24 meters, there will be few fish. We cannot get vitamins, and it affects fishermen economically negatively.*" S30

Examples of informal reasoning patterns for the SSI of plastic use are presented below.

Emotional reasoning pattern on the SSI of plastic use:

> "*In the use of plastic, it harms animals and causes their death, and various animals die and plastic is made from petroleum. I don't want plastic to be used. I would like plastic (bottles, bags, ear sticks, etc.) to be made of something else, not petroleum. I would like something that will not harm people and animals and will not infect them with poison*." S42

Intuitive reasoning pattern on the SSI of plastic use:

> "*The simplest example of the use of plastic is the pens we use, so I think it is illogical to oppose plastic when there is plastic even in these pens. It is a good thing economically because it enriches the country, as a production, as a society, I don't know because each person says something from a different decision, but I think it is important as a society, it is harmful to the environment, but we have to do it until something else is found*." S26

The observation findings revealed that participants were frightened by the possibility of an explosion at the planned nuclear power plant in Sinop. They referred to the Chernobyl Nuclear Power Plant explosion as a reason for their uneasiness. Accordingly, statements regarding reflecting the intuitive reasoning pattern were frequently observed. During the discussion on cryobiology, students often expressed disbelief in its success on humans, while acknowledging its potential usefulness against species extinction. Students who opposed cryobiology primarily cited religious reasons. Alongside statements emphasizing the importance of making their own decisions, students also expressed intuitive, rational, and emotional views. These included beliefs that cryobiology could help cure diseases, support *in vitro* fertilization treatment, yet also provoke fear of freezing themselves. Regarding the fishing activities, students frequently emphasized the importance of ensuring sustainability so that fish would be available for future generations. They also expressed concern about finding solutions and proposed innovations, such as limiting fishing depth to 21 m or designing nets that do not dredge the seabed. Statements reflecting the rational reasoning pattern frequently emerged during the discussion. In the discussion on plastic use, students highlighted its importance in electricity transmission and automobile production, noting its potential role in reducing global warming, as well as the benefits of recycling. They also frequently mentioned the harmful effects of plastics on marine organisms and their transfer through the food chain. In this SSI, the rational reasoning pattern was the most prominent. Findings on Socioscientific Reasoning of Secondary School Students in Local and General SSI.

All SSIs were rated separately for each aspect of socioscientific reasoning. The findings obtained in all SSIs regarding the complexity aspect of socioscientific reasoning are presented in Figure 3.

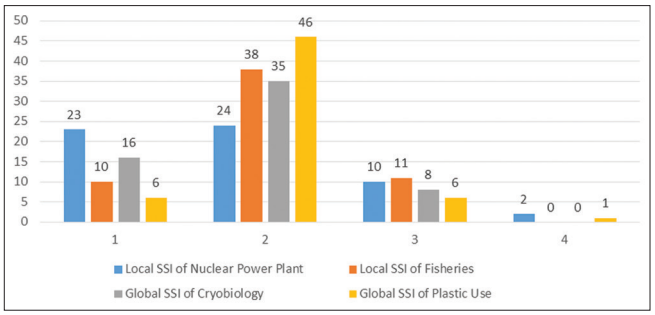

Figure 3: Findings on the complexity aspect of socioscientific reasoning in local and general socioscientific issues

Figure 3 shows that the 2nd level is most frequently dominant in middle school students' comprehension of the complexity aspect of socioscientific reasoning, with most responses clustered at this level. The findings indicate that students were able to recognize the pros and cons of the issue in the complexity aspect of SSIs, but they tended to approach the problem in a relatively simple way. The 4th level of complexity understanding appeared only in the SSIs related to nuclear power plants and plastic use, but not in others. In the context of local and general SSIs, 2nd and 3rd level reasoning was observed mainly in relation to nuclear power plants and fisheries, which are local SSI. Analysis of the graph by the order of SSI implementation shows a continuous decrease in 1st-level reasoning and a steady increase in 2nd-level reasoning. This suggests that, at the beginning of the study, students more frequently offered simple and illogical solutions, but their perception of complexity improved over time. Examples of student statements on the complexity aspect of socioscientific reasoning are presented below.

S16, showing 4th-level socioscientific reasoning regarding the establishment of a nuclear power plant in the city, considered its positive and negative effects, acknowledged the complexity of the issue, and expressed the following view: "*I want it not to be established because it causes consequences, such as air pollution and water pollution. Living things can be affected by this situation and lose their lives. We will have economic problems. Economically, we don't need to go abroad, so we don't owe money. Environmentally, radiation is emitted from power plants and gets into the soil. This affects the food we eat and can affect our health, and the fumes from the factory cause air pollution.*"

S49, showing 3rd-level socioscientific reasoning regarding cryobiology, approached the subject inquisitively, sought solutions to the issues considered complex or problematic, and expressed the following view: "*I think cryobiology can be useful both scientifically and economically. Benefits: In organ transplantation, by freezing the organs, it will be easier for doctors to transplant the organs to the patient. We can advance scientifically; I think it would be very good for space travel. My decision is ethical; it depends on people's decision. Some people think in terms of religion and some people don't mix religion with science. If it works socially, people can have*

a chance to see a loved once again, but that person will die anyway, but if it works when it is frozen and wakes up, it can be very useful for people, if it is frozen and wakes up dead, there is nothing to lose. If it's frozen and wakes up healthy, it's good for us and bad for other countries. Because we advance in science. But freezing the person will advance time. Technology, their family, environment, etc., will they be able to adjust when they wake up? Like this."

S15, demonstrating second-level reasoning in the complexity aspect of the Fishing SSI, addressed the pros and cons of the issue to identify the source of the problem and expressed the following view: "*It should be 24 m because there are eggs on the shores, and they can be damaged. Also, they should make the nets in such a way that eggs do not enter the nets, then only the fish will enter, that is, the eggs will not be damaged, and they should take it because it is a source of food for people. People pollute the seas and the waste from the industries flows into the seas, lakes and rivers and the fish are decreasing because people act unconsciously. Fishermen make a profit economically and because it is a source of food for people.*"

S7, demonstrating 1st-level reasoning in the complexity aspect of the plastic use SSI, evaluated the issue from a single perspective, without considering different viewpoints. The student expressed the following opinion: "*I think plastic should not be used, but it should be used without harming the environment and the environment, that is, it should be used without throwing it into the seas, it should not be used by throwing it into the seas, if we throw it into the seas, fish, etc., animals may die. So, let's not harm the environment and nature. I think if they throw plastic products into the sea, the fish may die and the turtles may mistake them for food and eat them, so economically we should not throw plastic products anywhere in the seas, in nature. Socially, we should not throw garbage on the ground. It can harm nature and other objects.*"

The findings obtained in all SSIs regarding the perspective aspect of socioscientific reasoning are presented in Figure 4.

As presented in Figure 4, most data in the perspective's aspect clustered at the 2nd level, indicating that students primarily evaluated the topic from a single perspective. However, the highest frequency was observed at the 3rd level in the plastic use SSI. In this SSI, students frequently expressed different perspectives. An equal distribution between the 2nd and 3rd levels was observed in the fisheries SSI. In a perspective aspect, it is seen that only in the nuclear power plant SSI, there were 2 students who evaluated the subject from perspectives, that is, at the 4th level. The findings suggest that students are able to make evaluations in the perspective aspect of socioscientific reasoning within the context of SSIs. This situation shows us that the number of students who cannot examine the problem carefully is less. It is seen that students can make evaluations in terms of the perspective aspect of socioscientific reasoning in the context of SSIs. When analyzed by local and general contexts, an increase at the 3rd level was observed in both the second local SSI and the second general SSI. Analysis of the graph according to the implementation order of the SSIs shows a consistent increase at the 3rd level. Below, student statements related to the perspective aspect of socioscientific reasoning are presented separately for each SSI.

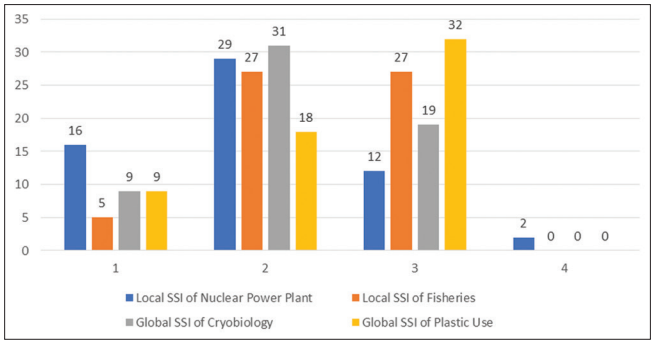

Figure 4: Findings on the perspective aspect of socioscientific reasoning in local and general socioscientific issues

For the nuclear power plant SSI, examples of student statements are as follows: S45, who demonstrated 1st-level reasoning, evaluated the issue superficially and expressed the following view: "*Others also say it should be built, there are a few who do not want it, but they also want it".* S16, who reasoned at the 4th level, evaluated the issue from perspectives and expressed his opinion as follows: "*A nuclear power plant to be established in Sinop concerns the whole of Turkey, that is, the surroundings of Sinop. The perspective of miners would be in favor of its establishment. Because coal is produced in nuclear power plants, they want it to be built. Doctors do not want it to be built because diseases will increase due to air pollution, water pollution, etc.*"

Examples of student statements regarding the perspectives aspect of socioscientific reasoning for cryobiology SSI are as follows: S8 showing 1st level skill: "*I think they can also look at this issue positively and affect science. It can be positive for science".* S51 showing 3rd level skill*: "Doctors may run out of patients and their salaries may decrease. A new job comes out and this job is to put people in capsules, and if this job is entered with an exam, they may want engineering and medicine. For example, the capsule of a man who wants to live after 50 years can be broken and this can be a crime of killing people, it can be a sin.*"

The findings obtained in all SSIs regarding the inquiry aspect of socioscientific reasoning are presented in Figure 5.

Figure 5 shows that, in the inquiry aspect, students are clustered at the 1st level and largely fail to recognize the need for inquiry. At the 4th level, no students demonstrated the ability to question. This finding indicates that students require further development in their inquiry skills. When evaluated in the context of local and general SSIs, no significant were observed across grade levels. Analysis of the graph according to the application order of SSIs shows an increase at the 1st level, which is considered undesirable. Examples of student

statements demonstrating 1st-, 2nd-, and 3rd-level skills in the inquiry dimension of socioscientific reasoning for the nuclear power plant SSI are illustrated in the graph.

Below are examples of student statements reflecting 1st-, 2nd-, and 3rd-level inquiry skills in the nuclear power plant SSI. S1, who reasoned at the 1st level, could not understand the need for inquiry and expressed his opinion as follows: "*I don't think I have missing information*." S41, who reasoned at the 2nd level, offers unclear suggestions for inquiry and expresses his opinion as follows: "*There are benefits as well as harms. For example, if there is leakage, it may harm the environment. But it is possible to minimize these. For example, the power plant can be built using the best materials. In this way, leaks can be minimized, not eliminated.*"

Examples of student expressions regarding the inquiry aspect of socioscientific reasoning for cryobiology SSI are as follows: S7, who showed 1st level skill, stated his opinion with the expression "*I guess it is not incomplete.*" S21 showing 3rd level of skill: "*Is an age restriction necessary for people doing cryobiology? Can cryobiology be done at lower temperatures? If it is done, can it come out of this capsule more quickly? These can be researched from the general network.*"

The findings obtained in all SSIs regarding the skepticism dimension of socioscientific reasoning are presented in Figure 6.

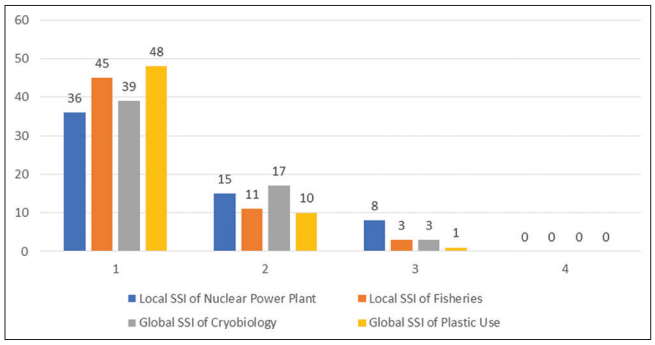

Figure 5: Findings on the inquiry aspect of socioscientific reasoning in local and general socioscientific issues

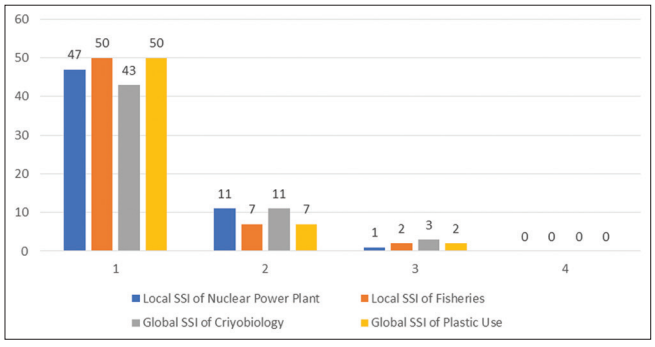

Figure 6: Findings on the skepticism dimension of socioscientific reasoning in local and general socioscientific issues

Figure 6 shows that, across all SSIs, students are clustered at the 1st level, while no students demonstrate skepticism at the 4th level. This shows that the students involved in the study fail to recognize the importance of the conflicts of interest between different stakeholders involved in SSIs or the positions taken by these stakeholders on SSIs. It is noteworthy that no significant differences were found between local and general SSIs. When the graph is analyzed according to the order of SSI implementation, no noticeable change is observed in students' skepticism. Examples of student statements about the socioscientific reasoning skepticism dimension of the Black Sea fishing activities SSI are as follows: S17 showing 2nd level skill: "*It is a little strange that we (in the Black Sea region) should consume more fish, but it is the least and below the average.*" S24 showing 3rd level skill: "*If it is 24 meters, will it affect economically? Do purse seiners take everything that is under water?.*"

Examples of student expressions regarding the socioscientific reasoning skepticism dimension of the plastic use SSI are as follows: S1 showing 2nd level skill: "*Are the garbage collectors doing their job, are the plastics in the sea collected?*" S55 showing 3rd level skill: "*It was said that plastic disappears in nature within 500 years and that it takes 800 years in the seas. I found this erroneous because I think plastic is consumed in a shorter time in terms of nature and can be removed from the seas in only 50 years.*"

CONCLUSION, DISCUSSION, AND RECOMMENDATIONS

Results on Secondary School Students' Informal Reasoning Patterns Related to Local and General SSI

Regarding informal reasoning patterns, it is observed that the frequency of decision-makers using intuitive patterns at the nuclear power plant SSI is higher than at other SSIs. This may be due to the fact that the nuclear power plant SSI is the first subject to be applied, as well as the fact that the reflections of the devastating effects of the Chernobyl nuclear power plant accident in the past are clearly seen by the people of this region. In addition, it is thought that this situation may also be related to the effects of the transfer of the experiences and teachings of the middle school students participating in the research on the subject from the past, and this may be the reason why they act more impulsively in the context of SSI. However, when looking specifically at the nuclear power plant SSI, students often made their decisions using rational reasoning. Similar to this study, Wu and Tsai (2011), in their research examining the relationship between high school students' cognitive structures and informal reasoning levels in the context of nuclear energy use, found that students had more than one perspective when making a decision about a topic, but unlike this study, they made their decisions based on evidence. In contrast to Wu and Tsai (2011), the younger age group in our study (middle school students) may have contributed to their greater use of

intuitive reasoning compared to other SSIs. However, beyond this, it was assessed that the SSI research on nuclear power plants conducted in Turkey's Black Sea coastal region may have created a context closer to the participants than Wu and Tsai's (2011) study, due to the Chernobyl disaster and the planned construction of a nuclear power plant in the city. This result demonstrates that exposure to negative outcomes of local historical events (Chernobyl) and sociological issues strengthens students' intuitive reasoning, thereby providing a new contribution to the literature on the role of local/personal context.

Another result of the study was that the emotional pattern was higher in cryobiology SSI compared to other SSIs. It is thought that cryobiology may have activated different cognitive-affective processes in students due to the fact that it is a subject related to health and has a more active sociological aspect, and individuals who can make rational-emotional decisions may tend toward the emotional pattern and suppress their rationality when the health factor comes to the fore. However, when we look specifically at cryobiology SSI, students have predominantly exhibited rational followed by emotional informal reasoning patterns. Similarly, Genç and colleagues (2020), in their study with middle school students, found that students who made positive decisions used their emotions, and that emotions, such as empathy and sympathy, were prominent in their findings regarding informal reasoning patterns related to tissue and organ donation. It was determined that those who made negative decisions mostly used logical reasoning. This finding shows that health-based SSIs, as well as general SSIs, make the emotional dimension dominant in students' reasoning, along with the rational dimension. This result supports and expands the literature that highlights the pedagogical role of emotions in SSI discussions. It was observed that the middle school students participating in the study used the rational pattern more frequently in the Black Sea fishing activities SSI. Our study reveals that students' more frequent use of rational reasoning in SSI (such as fishing) directly related to their environment, indicates that the local context plays a supportive role in cognitive processes. In the plastic use SSI, rational reasoning was the most frequently observed, whereas emotional reasoning was the least used.

Our findings indicate that the SSI context plays a critical role in determining the reasoning patterns used by students. When the SSI context is examined locally and globally, rational reasoning patterns were used most frequently when all SSIs were considered separately. However, when looking at all SSIs holistically, it was found that rational reasoning was most prevalent in fishing and plastic use, intuitive reasoning in nuclear power plants, and emotional reasoning in cryobiology. In other words, beyond a clear distinction based on local and general contexts, it was found that students' experiences (nuclear power plants) and the emotional dimension of the subject (cryobiology), or the fact that the SSI context directly or indirectly affects life (plastic use and fishing), influenced the use of intuitive and emotional reasoning patterns in informal reasoning.

Contrary to the results of this study, Özden (2020), in his study examining the informal reasoning of elementary school students about SSIs, utilized the context of organ transplantation, recycling, and the use of forest areas SSIs. They found that the least used reasoning pattern was rational, and the most frequently used reasoning pattern was intuitive. In addition, it was understood that the fact that the students had experience with SSIs, in other words, the fact that SSIs were local, could enable them to have more rational-emotional patterns. Regarding the differentiation of students' informal reasoning with the effect of locality and generality, it was observed that local SSIs had more effect on the development of rational pattern in students, while general SSIs had less effect. This shows that local SSIs have a greater effect on rational reasoning skills. Again, it was determined that local SSIs reduced the intuitive pattern, while this was not the case for general SSIs.

Similar to this study, Atasoy et al. (2019), in their study conducted with 7th-grade middle school students, stated that students can reason by adopting the perspective of the role they assume and that it can be concluded that the justifications they produce while making decisions about SSIs are affected by different contexts. Similar to this study, Can (2021) examined the effect of socioscientific subject context (local and general) on the argument quality of 8th-grade middle school students in his study. According to the results of the analysis, there was no statistically significant difference between local and general contexts, both within and between groups in total score, data/justification, and refutation scores. The results of our research contribute to the literature by demonstrating that there are variables beyond the local and general context.

Results on Secondary School Students' Socioscientific Reasoning about Local and General SSIs

In the complexity dimension of socioscientific reasoning, it is seen that the students mostly made evaluations at the 2nd degree. According to this, the participants of the study were able to consider the positive and negative aspects of SSI, address the problem simply, and see a single solution. In the complexity dimension of socioscientific reasoning, it was determined that the 2nd and 3$^{rd°}$ were higher in local SSIs than in general SSIs. This result demonstrates that students have a deeper understanding of complexity in local SSIs, highlighting the role of context in enhancing complex reasoning. In the multiple perspectives dimension, it is seen that students mostly have socioscientific reasoning skills at the 2$^{nd°}$ and then at the 3$^{rd°}$. In the multiple perspectives dimension, it was understood that local SPSs, such as nuclear power plants and fisheries, could be evaluated more frequently at the second level, and general SPSs, such as cryobiology and plastic use, could be evaluated more frequently at the third level. This result shows that students can incorporate more diverse perspectives in general SSIs but remain more limited in local

SSIs. This situation reveals that context is critical in shaping perspective-taking.

Our research showed that there were no students at the 4th° in inquiry and skepticism dimensions of socioscientific reasoning, and most of the students were able to make decisions with 1st° inquiry and skepticism. In other words, the participants of the study could not understand the need for inquiry. They also failed to recognize the positions taken by different stakeholders in the scenarios and the conflicts of interest between these stakeholders. This result shows that middle school students are developmentally limited in terms of inquiry and skepticism, and that teacher influence and age factors reinforce this limitation. This situation highlights the need to build skepticism and inquiry skills at an early age.

As a result of their research, Romine et al. (2020) state that perspective taking is the necessary bridge between students' understanding of complexity and their competencies of higher-order inquiry and skepticism. Romine et al. (2017) stated that there is a hierarchical structure in students' socioscientific reasoning competencies. They argued that the sub-dimensions of inquiry and skepticism are higher-level reasoning skills. It is also thought that the inadequacy in the skepticism dimension of the study stems from the fact that the study group was conducted by their own teachers and that they did not have enough experience and knowledge that they should look at such a situation with suspicion due to their age group.

Suggestions

Since the present research is a case study requiring short-term interaction, future research can examine the informal reasoning and socioscientific reasoning of middle school students by providing longer-term interaction.

For students to use emotional, rational, and intuitive reasoning modes together and to develop more perspectives and improve their informal and socioscientific reasoning, it is recommended to include SSI scenarios with local SSIs in curricula and textbooks.

By their nature, qualitative studies are not generalizable in terms of the results obtained since they are conducted with a relatively small number of participants. For all these reasons, it is thought that it would be beneficial to increase research on reasoning skills with middle school students. Future studies should expand to larger, more diverse student populations and employ mixed methods approaches to enhance both depth and generalizability.

According to our findings on the impact of both local and general SSI on judicial processes, it is recommended that scenarios on both local and general SSIs should be included in curricula and textbooks for students to develop their reasoning skills, gain perspective, make inquiries, and see the impact of different stakeholders.

The results suggest that SSI-based instruction should not rely solely on the local–general distinction but should also consider students' prior experiences, the emotional relevance of health-related issues, and the everyday-life impact of topics. Incorporating such contexts into curricula can support the balanced development of rational, emotional, and intuitive reasoning.

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