Science & Education
https://doi.org/10.1007/s11191-026-00754-4

ARTICLE

The Use of Concept Cartoons on Socioscientific Issues to Promote Teachers' Dialogic Discussions: Developing Gifted Students' Decision-Making Competences and Informal Reasoning Modes

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Accepted: 7 May 2026
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Abstract
This study aimed to examine teachers' dialogic discussions in applications of concept cartoons on socioscientific issues (SSICCs) and how these discussions developed high school gifted students' decision-making competences and informal reasoning modes. Through multiple case design, this study viewed three teachers in Science and Art Center (SAC) as the cases. The teachers' dialogic discussions were analyzed by using the Dialogic Inquiry Tool (DIT). The findings of multiple case analysis revealed that the teachers' dialogic discussions ranged from the lowest dialogic level to weak level in the first weeks. Toward the end of the implementations, they demonstrated strong semi-dialogic level discussions. Likewise, high school gifted students evolved their decision-making competences from spontaneous decision-making level to the intermediate level of metareflection over time. This suggests that the teachers' pedagogical improvements in dialogic discussions via SSICCs have positively impacted high school gifted students' decision-making competences and informal reasoning modes. It can be concluded that an improvement in the teachers' dialogic discussions via SSICCs has stimulated the students' decision-making processes, which cover the use of the scientific evidence and multiple disciplines to form their informal reasoning modes. Thus, it is suggested that professional development programs should be developed and implemented to cultivate in-service teachers' pedagogical competences at blending well-known educative tools (e.g., concept cartoons) with contemporary pedagogical strategies (e.g., dialogic discussion).

Keywords Concept cartoon · Decision-making competence · Dialogic discussion · Informal reasoning mode · Socioscientific issue

1 Introduction

Issues such as nuclear energy, climate change, and genetic cloning are considered socioscientific issues (SSI) because these issues include societal aspects in science. Addressing these issues in science courses and engaging students with argumentation to negotiate and

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resolve them are seen as important attributes for future citizens, who can develop functional scientific literacy using informed decisions about SSI (Çalik & Wiyarsi, 2025; Ozturk & Yilmaz-Tuzun, 2017; Zeidler et al., 2019). Informed decisions about SSI can be achieved when students analyze, synthesize, and evaluate data derived from multiple disciplines by using their moral and ethical considerations. Developing these skills varies among students because learning settings involve students with a wide range of characteristics as background, culture, interest, learning speed, ability, etc. (Tomlinson, 2014) and different learning needs resulting from this variety. So, it makes sense to adopt an inclusive approach for these diverse learning demands (Ranbir, 2024). For example, gifted students, characteristically, have different learning needs, demands, and expectations (Kapıcı & Coştu, 2023; VanTassel-Baska et al., 2021). Although they are not a homogeneous group (Reis & Renzulli, 2009), many gifted students are morally sensitive (Lovecky, 1997; Silverman, 1994) and have superior observational skills (Karnes & Riley, 2005), the ability to identify hardly detectable problems (Meador, 2003), and the ability to understand and apply scientific concepts (Gould et al., 2003; Ngoi & Vodracek, 2005). Therefore, these skills and abilities increase their potential to creatively solve everyday life problems. Additionally, most of them are eager to solve complex and controversial problems, analyze them by using scientific evidence derived from different disciplines, and discuss them with their classmates (Samardzija & Peterson, 2015). Thus, their inherent curiosity for scientific exploration could be used to heighten their sensitivity and awareness of societal issues (Porter, 2005; Silverman, 1994) and increase their motivation to engage with SSI (Karnes & Riley, 1999). Meanwhile, even though moral sensitivity and moral motivation are prerequisites for moral judgment, high intellectual ability may not predict mature moral judgment (Tirri & Pehkonen, 2002). Hence, Tirri and Pehkonen (2002) have suggested that teachers should support the moral development of gifted students by improving their moral reasoning skills and enabling them to discover the ethical aspects of SSI. Consequently, considering the general characteristics of gifted students, emphasizing SSI in science lessons through dialogic discussions can enable them, like all students, to learn scientific concepts meaningfully, realize the relevance of science to their lives, and make informed decisions about SSI.

SSI are considered controversial in nature because they have both scientific and social dimensions, open-ended, ill-structured problems, and not having precise answers (Kolsto, 2001; Sadler, 2004; Sadler & Zeidler, 2005). Because of these characteristics, Zeidler (2014) has pointed out the importance of using scientific evidence to address controversial nature of these issues and reach informed decisions about them during SSI teaching. In other words, making informed decisions during SSI teaching requires students to engage in dialogic discussion and debate, which, in turn, asks the use of scientific knowledge/evidence that has social implications. Dialogic discussions not only pose a high student–student interaction but also make communication(s) between students and teachers two-way and equal (Clarke et al., 2016; Kıryak et al., 2024). Teachers have an essential role in implementing dialogic discussions because they are the primary decision-makers in providing discussion opportunities that allow students to collaborate in groups and participate in dialogic discussions (Duschl & Osborne, 2002; Rapanta, 2021; Zaccarelli et al., 2018). Atasoy et al. (2022) pointed out that there is a continuum for discursive communications between teachers and students from monologic to more dialogic discussion. One end of the continuum includes authoritative teachers' profiles, in which teachers disseminate information and evaluate students' responses. Its other end contains dialogic interactions between teachers and students in which teachers initiate and maintain social negotiations by asking for clarification of students' ideas and giving the responsibility of learning to the students. In this way, the students need to

perform reflective thoughts for the responses elaborated by each member in the class. Researchers, who focused on SSI teaching, classified teachers' communication roles in the dialogic discussions either dialogic or monological/authoritarian (Bossér & Lindahl, 2019, 2021; Kilinc et al., 2017; McNeill & Pimentel, 2010; Reznitskaya et al., 2012). These researchers argued that having more dialogic discussion in classrooms makes their learning environments more challenging for both teachers and students. In fact, such a challenge calls enriching alternatives for gifted students to employ dialogic discussions and argumentations in their learning environments. Consequently, gifted students will also benefit greatly from this challenge, along with other students.

In Türkiye, Science and Arts Centers (SACs) offer project-based, interdisciplinary, and enriched after-school programs catering to the nuanced learning needs of gifted students from primary to high school (Sak, 2013). Within SACs, science education is differentiated for gifted students by immersing them in the challenges of the scientific method. This tailored approach is crucial for all students as well as gifted ones in concept learning and connecting these concepts to real-world problems/issues by using higher-order thinking skills (Çelikdelen, 2010). Therefore, integrating SSI into science instruction at SACs, where gifted students engage in dialogic discussions, is a good strategy to address their learning needs.

Concept cartoons can be used as an alternative teaching tool to enhance teachers' dialogic discussion practices. In this dialogic discussion, students are encouraged to share scientific evidence both displayed in concept cartoons and they reached through their own search (Naylor & Keogh, 2000). In SSI teaching, concept cartoons can help dialogic discussions by presenting a problem situation or issue along with claims and counterclaims. For each claim, justifications from different disciplines can be provided. Thus, students can evaluate the issue from multiple disciplines and make informed decisions. Moreover, concept cartoons are also used as essential instructional tools to make students take the initiative in offering various alternative scientific explanations besides those in conversation boxes (Pekel, 2019; Yapıcıoğlu & Kaptan, 2017). All these practices strengthen students' decision-making processes by allowing them to negotiate and resolve issues from multiple disciplines. However, there are also some disadvantages of using concept cartoons. Researchers stated that some students may have greater desire to participate in discussions. This may inhibit other students' participation and leave them passive. Moreover, some students may struggle to engage in discussions due to limited scientific vocabulary or verbal skills, or low self-confidence to explain their ideas aloud (Keogh & Naylor, 1999). To overcome these disadvantages, teachers' ability to manage the discussion acts as a milestone.

This study aimed to use concept cartoons on socioscientific issues (SSICCs) in dialogic discussions within SSI teaching to determine how gifted students develop their decision-making competences and types of their used informal reasoning modes. More specifically, it intended to investigate the relationships between SAC teachers' dialogic discussions in implementing SSICCs and gifted students' decision-making competences and informal reasoning modes. The specific research questions (RQs) focused on this study were as follows:

RQ1: How do teachers' dialogic discussions change over time and in relation to different SSICCs for gifted students?
RQ2: How are gifted students' decision-making competences affected by their engagement with dialogic discussions using SSICCs?
RQ3: How are gifted students' informal reasoning modes affected by their engagement with dialogic discussions using SSICCs?

2 Theoretical and Conceptual Frameworks of the Study

2.1 Dialogic Discussions in SSI Teaching

Engaging in dialogic discussions in SSI teaching helps create a constructivist-learning environment (Vygotsky, 1987) and supports sociocultural interaction (Kelly & Chen, 1999). Researchers argued that a constructivist-learning environment fosters students to learn from their peers and do critical reflection on their own ideas as well as others. Thus, learning is achieved through social interactions among students and between students and teachers. During these social interactions, students share their ideas, beliefs, mode of thinking, and everyday experiences. Thus, dialogic discussions not only facilitate their knowledge construction through science learning but also encourage them to share their gained experiences from different environments. However, researchers noted that this discussion approach places complex demands on both teachers and students (Kumpulainen & Rajala, 2017). The use of this dialogic discussion in SSI teaching further complicates this demand. That is, while students express their ideas, they also reveal their identities (e.g., beliefs, values, ethical/moral considerations) as they position themselves and their actions within their own narratives (Bossér & Lindahl, 2019). Fostering open and respectful interactions among students helps them engage with alternative ideas, construct their own ideas by evaluating the ideas of others, and change their ideas if necessary (Scott et al., 2006). As they become more accustomed to expressing themselves freely, they also feel that they are valuable members of the learning community.

Reznitskaya (2012) described the characteristics of the dialogic teaching practices based on social-constructivist theory of learning. Then, considering these characteristics, the researcher developed an observation scale to anchor class talk and named it as Dialogic Inquiry Tool (DIT). The researchers have generally used the observation scale to capture the key features of discussion environments across the spectrum from monologic to dialogic (Engin & Donanci, 2015; Kathard et al., 2015). Like earlier researchers, in this current study, DIT was used as an analytic tool to address complex characteristics of dialogic discussions in SSI teaching.

Although SSI teaching requires dialogic discussions and discourses, most science teachers generally prefer monologic discussion. This monologic discussion generally includes authoritative talk in which teachers directly transfer the content knowledge to the student, use superficial question–answer-feedback relationships, teach concepts in a disconnected way, and do not allow student–student communication (Kilinc et al., 2017). Researchers found that teachers tended to use limited dialogic discussions due to their ongoing monologic discussion habits (Atasoy et al., 2022; Bossér & Lindahl, 2021; Kilinc et al., 2017; Shi et al., 2021) and preferred more semi-dialogic discussions while trying to establish a balance between monologic and dialogic discussion preferences (Atasoy et al., 2022; Scott et al., 2006). Across the spectrum from monologic to dialogic discussion, semi-dialogic discussion refers to an intermediate stage in which a teacher takes some positive steps toward a dialogic approach (e.g., asking more open questions, allowing students to explain at greater length) but does not fully embrace other elements necessary for dialogic discussion (e.g., strategic use of feedback, sharing of authority, meta-level reflection, connected construction of ideas) (Reznitskaya, 2012). Dialogic discussion in the classroom is built upon teacher–student and student–student interaction dynamics. During the dialogical discussion, the teacher is expected to listen to students' thoughts and encourage the emergence of different viewpoints by asking open-ended and authentic questions such as "Why

do you think that?," "Do you have any other evidence?," or "Does anyone else agree with this idea?" (Reznitskaya, 2012). Instead of simply evaluating students' responses as "right" or "wrong," the teacher should use these responses as data to deepen the discussion (Scott et al., 2006). The teacher extends the chain of discussion by using a student's idea and passing it on to another student. Thus, students are expected to listen to each other's ideas, challenge these ideas, or develop them. In this process, students are positioned as "independent learners" and "legitimate participants" (Bossér & Lindahl, 2019). The teacher asks students not just to defend an idea based on their personal opinions, but to present evidence and logical reasoning to support that opinion (Reznitskaya, 2012). Students adopt their peers' claims, combine them with their own evidence (data), and synthesize them to construct new meaning (Scott et al., 2006).

The research findings supported that dialogic discussion in the class attained when teachers provided an independent and authentic learning environment by facilitating students' engagement rather than dominating the class (Gilson & Sauder, 2021; Sosa & Sullivan, 2013). Hennessy et al. (2023) also supported that more dialogic teachers created a learning environment where open classroom climate for learning through dialogue was encouraged. Martin and Hand (2009) reported that a teacher, who attended a 2-year professional development program, initially showed a monologic tendency to focus on the question-answer-feedback relationship based on the subject content and did not include student interaction. However, as the program progressed, the teacher followed a more dialogic discussion, where evidence and claims were put forward, in-depth questions were asked, and students' participation was increased. They concluded that transitioning from monologic to dialogic discussion was a long and challenging journey. In their dialogic tendency-oriented studies, which turned instruction into an autonomous and cognitively engaged classroom interaction process, Sedova et al. (2016) discovered that when teachers used the dialogic discussion method, students in the observed classrooms were able to present high quality arguments and engage in challenging thinking processes. Zaccarelli et al. (2018) investigated a teacher's use of argumentation approach in dialogic discussion. The teacher stated that changing her instructional practices in a way of encouraging students to express their arguments by using science concepts, and considering students' claims and evidence as well as alternative ideas and evidence took prolonged practices. Zaccarelli et al. (2018) concluded that allocating more time to professional development was important to improve teachers' pedagogical skills in dialogical discussion. McNeill and Pimentel (2010) further supported that when the dialogic discussion was effectively used in SSI teaching, students used various evidence (scientific, personal, etc.) to support their claims, expressed their reasoning, and made informed decisions about whether climate change exists.

Similar to these students, gifted students also become more proactive in initiating change and engaging in deeper discussions with their peers when their learning environments allow them to have a greater autonomy (Netz, 2014). However, Choi and Yoon (2014) argued that gifted students have little experience in such learning environments, where open-ended inquiry ends with discussion and dialogic interactions. In contrast, Akbaş and Çetin (2018) determined a change in the quality of gifted students' informal reasoning about SSI that allow dialogic interactions, because these interactions not only enabled gifted students to question each other's ideas but also helped them provide feedback to each other and learned more permanently (Kelly & Takao, 2002). Therefore, dialogic discussion of SSI can be a powerful way to boost gifted students' intrinsic motivation for learning. This autonomous motivation can also foster their sensitivity to environmental and societal issues through discussions of SSI. Later, this sensitivity can be transformed into personal meaning in their lives (Betts & Kercher, 2009; Corpus et al., 2009). So, by

engaging with SSI, they can be more likely to be active, reflective, and put extra effort to understand the complex nature of SSI.

Grappling with complex characteristics of SSI through the dialogic discussion can lead to a deeper understanding, development of higher-order thinking skills (Levrini et al., 2021) such as "formulating, defending, and scrutinizing each other's viewpoints" to address multiple perspectives (Reznitskaya, 2012, p. 448), and negotiation of SSI collectively. Negotiating SSI includes the ability to analyze an issue and potential solutions by considering the perspectives of different stakeholders and knowledge derived from multiple disciplines. One's perspective refers to how this individual perceives and interprets an issue. Thus, it was argued that students can achieve an effective discussion of an SSI by considering knowledge gained from different scientific disciplines, ideas and opinions acquired from non-scientific disciplines, and multiple perspectives held by different stakeholders. Furthermore, an SSI-based argument generated by students in the dialogic discussion also requires consideration of other aspects such as local, global, social, and physical realities (Zeidler et al., 2019). Specifically, the complexity of SSI provides the intellectual challenge necessary to enhance the performance of gifted students (Levinson, 2007) by focusing on their deeper, more abstract and complex learning needs (Kaplan et al., 2016). In the dialogical discussion environment, students can also exchange ideas about their own perspectives and share how they have developed them. All these engagements require explanation of thinking and co-construction of knowledge (Hennessy et al., 2023), which confront them with intellectual challenges. So, this could move science learning beyond the individuals' capabilities (Reznitskaya & Wilkinson, 2021). Therefore, this study formulated its research questions to address how gifted students can use informal reasoning generated from multiple disciplines, multiple perspectives and experiences in a dialogic discussion environment.

2.2 Use of Concept Cartoons on Socioscientific Issues (SSICCs)

Concept cartoons are cartoon-style drawings that reflect students' daily life experiences with various science concepts and include mutually alternative explanations of three to four people in conversation boxes (Naylor & Keogh, 2000). The existing literature has shown that concept cartoons can be used for students at various ages and abilities, contribute to the development of the students' higher-order thinking skills and decision-making skills, and enable them to engage in dialogic discussion by presenting alternative explanations in conversation boxes (Atasoy & Ergin, 2017; Atasoy et al., 2020; Cavagnetto & Hand, 2012; Chin & Teou, 2009; Kabapınar, 2009; Naylor et al., 2007; Webb et al., 2008). Likewise, gifted students can also get similar benefits from using concept cartoons. For instance, stimulating gifted students' curiosity and engagement, concept cartoons foster them to connect more deeply with real-world problems and develop higher-order thinking skills. Therefore, they better meet the learning needs of gifted students than standard textbooks and curriculum (Bain et al., 2003; Newman, 2008; VanTassel-Baska, 2010; VanTassel-Baska & Stambaugh, 2006). According to Johnson et al. (1995), basic textbooks fell short of science learning requirements for all students including gifted ones. The researchers also stated that related curriculum should include materials that sufficiently handle depth and complexity of different learning needs, e.g., learning characteristics of gifted students. In this sense, concept cartoons can be seen as one of the instructional materials to foster the development of decision-making skills for SSI and facilitate dialogic discussions by presenting alternative explanations (Atasoy & Ergin, 2017; Cavagnetto & Hand, 2012).

Even though researchers see scenarios as a primary focus for SSI teaching, they have recently employed concept cartoons to enrich in-class discussions by providing plausible alternative ideas about an SSI in conversation boxes (Atasoy et al., 2022). The conversation boxes in concept cartoons provide a platform for students to express their surprise, question alternative ideas, and challenge each other's ideas (Naylor & Keogh, 2000). This platform also offers a dialogic process based on teacher–student and student–student interactions, where answers are sought to open-ended questions and focused on justified explanations (Bossér & Lindahl, 2021; Chin & Teou, 2009). In the context of this study, alternative ideas in informal reasoning modes, which included knowledge generated from different disciplines, were provided in the conversation boxes.

Since differentiated instruction aims to maximize the learning potential of all students in the classroom, teachers adapt content, process, product, and learning environment to respond to differences in readiness, interest, learning speed, and learning profiles among the students (Tomlinson, 2014). For gifted students, any differentiated instruction should include five interrelated concepts to guide adjustments or programs: challenge, choice, interest, enjoyment and personal meaning (Gentry & Ferriss, 1999). Concept cartoons challenge students' thoughts while supporting the development of their understanding and reasoning skills (Naylor & Keogh, 2013). As a part of this challenge, these tools give students a discussion environment that encourages them to think critically and participate in discussions (Atasoy et al., 2022). Also, their visual components not only make science subjects joyful to understand but also improve critical thinking abilities by generating arguments for situations that arise in daily life (Gunay Balim et al., 2014; Naylor & Keogh, 2000). This link between issues selected from daily life and science teaching creates personal meaning as well. Thus, differentiated instruction with concept cartoons are ideal for the gifted students to allow them to have fun with their challenged elements (Naylor & Keogh, 2000), increase their intrinsic motivation, and develop their ability to apply these concepts in various contexts (Rule & Montgomery, 2013). Therefore, in this study, concept cartoons were used to capture the attention of gifted students and spark their curiosity by presenting informal reasoning modes derived from multiple disciplines on the SSI.

2.3 Decision-Making Competences and Informal Reasoning Modes in SSI Teaching

Decision-making, as a multi-stage process, requires students to use data and evidence for determining the most appropriate alternative solution(s) of a given problem (Bravo-Torija & Jiménez-Aleixandre, 2018; Dauer et al., 2022; Jimenez et al., 2023). High-quality decision-making in SSI depends on the decision-makers' skills to understand scientific knowledge or other information and choose trade-offs based on priorities among multiple solutions (Alred & Dauer, 2020; Dauer et al., 2022; Wilson & Arvai, 2006). Phrased differently, these skills require students to consider and compare the advantages and disadvantages of multiple solutions and use trade-offs as a compensatory (high quality) decision-making strategy in which positive aspects of an option compensate for negative aspects. Trade-offs are an important factor of decision-making competence as they allow decision makers to focus on the rationale for choosing some options and rejecting others (Böttcher & Meisert, 2013). Researchers described four basic skill sets for the decision-making competences: assessing beliefs, assessing values, integrating beliefs and values, and having a meta-cognitive understanding (Parker & Fischhoff, 2005). Some studies investigated the role of trade-offs on decision-making (Dauer et al., 2022; Eggert & Bögeholz, 2010; Jimenez et al., 2023; Kahn & Zeidler, 2019), while other studies mostly examined students'

decision-making competences by focusing on the relationship between cognitive skills and decision-making skills (Bruine de Bruin et al., 2007, 2020; Pedretti, 1999). For example, after examining how students interpreted and evaluated mining as an SSI, Pedretti (1999) found that students' curiosity about science and technology, use of critical thinking skills, and decision-making skills were all important in addressing the issue of mining. The studies focusing on decision-making skills used both structured and unstructured questions. The multidimensional and uncertain nature of SSI require open-ended questions rather than structured questions to address students' decision-making competences. Lee's (2007) study, which focused on smoking as an SSI and aimed to develop students' decision-making skills, found that developing students' decision-making skills was a complex process. The researcher used open-ended questions to engage students in class discussions, encourage them to examine scientific evidence by considering trade-offs, help them to establish their own perspectives through value clarification, evaluate their views considering other perspectives/ideas, and avoid biases. Thus, the current study purposed to investigate gifted students' decision-making competences for different SSI by using open-ended questions and handling the use of evidence displayed in the concept cartoons.

Eggert and Bögeholz (2010) suggest a gradual increase in decision-making competences with respect to the use of and reflection on decisions: spontaneous level, low level of metareflection, intermediate level of metareflection and high level of metareflection. This classification indicates how deeply students can think about the structure of their decision-making processes and how well they can identify possible shortcomings in these processes. Spontaneous decision-making competence involves emotionally/intuitively decisions without reasoning at low level of metareflection. Similarly, noncompensatory decision-making competence includes low level of metareflection. Noncompensatory and compensatory decision-making strategies (use of cutoffs and trade-offs) consider evaluating multiple options at an intermediate level of metareflection. They ask students to have the ability to compare and contrast the advantages and disadvantages of multiple options presented in students' informal reasoning. This level is called as a mixed strategy and represents a transition from noncompensatory to compensatory (Böttcher & Meisert, 2013; Eggert & Bögeholz, 2010). Compensatory decision-making strategy (use of trade-offs) contains multiple options at a high level of metareflection with explicit weighing/comparing criteria of trade-offs. However, decision-making on SSI during class interaction can lead to the application of highly complex strategies involving many important aspects of the problem. Since gifted students have multiple reasoning on complex problems, superior observation skills (Karnes & Riley, 2005), and the ability to detect hardly noticeable problems, they may transfer their innate characteristics to their decision-making processes concerning SSI. Thus, this study used Eggert and Bögeholz's (2010) classification to make these strategies visible.

As stated earlier, students use informal reasoning in their decision-making processes on SSI. Informal reasoning involves generating and evaluating arguments to address complex problems that have no clear-cut solutions (Means & Voss, 1996; Zohar & Nemet, 2002). Contrary to formal reasoning, informal reasoning focuses on intuitive and moral reasoning along with rational and emotive reasoning in arguments (Kuhn, 1993; Sadler & Zeidler, 2005). Likewise, because SSI lead to dilemmas and discussions in society, resolving and negotiating these issues require comparing arguments that include evidence derived from different sources (e.g., scientific, non-scientific disciplines–Zeidler et al., 2019; and multiple options–Eggert & Bögeholz, 2010) and employ different dimensions (e.g., political, social, ecological, ethical, moral, and psychological) (Sadler, 2004; Topçu et al., 2011). Recently researchers have used informal reasoning modes to address multiple disciplines and classify participants' arguments

in terms of informal reasoning. For example, Patronis et al. (1999) investigated high school students' informal reasoning modes regarding the construction of a road as an SSI and found four different informal reasoning modes (namely, social, ecological, economic, and practical). Yang and Anderson (2003) and Wu and Tsai (2007) examined high school students' informal reasoning modes regarding nuclear power plants in different contexts. The former study found scientifically oriented, socially oriented, and equally disposed informal reasoning modes while latter one revealed social-oriented, ecological-oriented, economic-oriented, and scientific and technological-oriented reasoning modes. The aforementioned studies reported that students hold different informal reasoning modes for different SSI.

As well as the studies with typical (normal) students, a few studies were conducted with gifted students to determine their informal reasoning. Means and Voss (1996) revealed that gifted students possessed considerably better informal reasoning than students with average and low abilities. In line with this, Akbaş and Çetin's (2018) research with gifted students underscored the connection between subject knowledge and informal reasoning ability. Şenel-Zor et al. (2025) reported that gifted students used high-quality informal reasoning when making decisions about SSI and were more likely to use rational informal reasoning than emotional informal reasoning. Additionally, the findings also highlighted the influence of personal experiences, emotions, and moral considerations on informal reasoning. Jang and Jang (2023) explored how gifted elementary students use evidence and the challenges they face while making decisions. They identified four informal reasoning modes: rational, emotional, intuitive, and mixed (as combinations of three reasoning modes). In Tirri and Pehkonen's (2002) study, gifted students used different reasoning modes when discussing the same moral dilemma. Further, they emphasized that the principles and values used for solving the dilemma revealed differences in the students' moral sensitivities. The researchers concluded that teachers should support the moral development of the gifted students by letting them explore and discuss ethical aspects of scientific work. Cho et al. (2008) found that gifted students actively questioned the opposing side's evidence and pointed out its weaknesses during discussions. However, they typically used weak arguments based on low-level evidence, such as personal experience or opinion, rather than objective evidence, to support their own claims. The researchers concluded that there should be more debate spaces and a greater emphasis on the instruction of scientific argumentation to maximize students' potential. Further, they suggested that this instruction should be enriched with diverse resources, tools, and materials that offer various reasoning modes.

Use of informal reasoning modes to present alternative ideas in concept cartoons can initiate and extend students' discussion. Chin and Teou (2009) revealed that students had to evaluate what other characters (conveying opposing views and information from different disciplines) said, while simultaneously supporting the accuracy of the statements presented by the character in the concept cartoon. During these evaluations, the students proposed explanations to support their claims and justified their reasoning by using data and evidence. Furthermore, they improved their thinking skills by presenting alternative perspectives and criticizing their peers' ideas during rebuttal. Throughout this discussion, they did not feel limited by the information given in the concept cartoons. The present study employed SSICCs to stimulate teachers' dialogic discussions in classroom learning environment and intended to enrich the discussions with the multiple disciplines presented in the concept cartoons. Based on all these practices, this study aimed to understand how these discussions develop decision-making competences and informal reasoning modes of high school gifted students.

3 Methods

3.1 Study Design

This research was designed as a case study to focus on teachers' in-class dialogic discussions. Case study is a qualitative research approach in which the researcher identifies conditions and themes related to the case by examining one or more situations in depth with multiple data collection tools (Creswell, 2007; Merriam, 1998). Case study incorporates a single case or multiple cases (Yin, 1984). In this study, multiple case study design was used in which the dialogic discussions of three SAC teachers were examined in detail by comparing the similarities and differences in their practices regarding different SSICCs implemented throughout a year. Moreover, how these practices were connected to the gifted students' decision-making competences and informal reasoning modes were also investigated.

3.2 Participants

The participants of the study were three teachers at a SAC and their gifted students. The teachers' experiences ranged from 8 to 29 years, and the students' ages were between 14 and 18 years. The teachers attended a teacher-training program as a part of this study. A total of seven teachers participated in the training program, and three of them and their students agreed to participate in this study voluntarily (Table 1). These students had attended SAC for 5 five to 7 seven years. Throughout the study, the teachers were observed and assisted with ongoing pedagogical support when they needed.

After getting official permissions from the directorate of provincial national education, and ethics committee of the university, the researchers informed the participants and their parents about the scope and procedure of the study and obtained consent forms signed by the parents. Codes and pseudonyms were used for the students and teachers to conceal real identities. For example, the pseudonyms Nehir, Ela and Murat were used for teachers; codes such as student 1, student 2, and student 3 were used for students.

Two teachers were female and one teacher was male. In SAC, high school students take biology, physics, and chemistry courses in grades 9 to 12. Teachers Nehir and Ela's classes included three students in each from grade 9. Teacher Murat's class had two students from grade 12 and one student from grade 11. This arrangement was done by the school administration according to the students' abilities. Also, the teachers have had different experiences regarding project works. For example, Nehir worked on disaster management and disability-friendly projects and organized science fairs; Ela also worked as a principal investigator at Erasmus + KA201 School Without Walls (Poland, Türkiye, Romania, Greece). All teachers had roles as consultants in a variety of project competitions.

3.2.1 Study Context

A total of 279 SACs in Türkiye provide educational practices to students (from grades 2 to 12) in terms of adaptation, supportive education, recognizing individual talents, developing talents, and project production and management. In our study, high school gifted students were in the process of project production and management, which required them to carry out an original project to solve a problem under the supervision of the teacher (Ministry of National Education (MoNE), 2019). The teachers working in SACs are determined by

Table 1 Some demographic characteristics of the teachers and their self-declarations about interest area and frequently used strategies and methods

Teacher	Gender	Teaching area	Teaching experience/SAC experience	Degree	Interest area	Frequently used strategies and methods	Number and grades of students
Nehir	Female	Science	8/2	Master (PhD ongoing)	• Ecology, • Recycling	• Problem solving • Argumentation • STEM	3 students from grade 9
Ela	Female	Biology	29/20	Undergraduate	• SSI • Biotechnology • Biochemistry	• Project based learning • Problem-solving • Cooperative learning • Purdue Model for gifted students • Outdoor learning	3 students from grade 9
Murat	Male	Physics	14/2	Master	• Software • Robotics • Electronics	• Experimental designs	2 students from grade 12 1 student form grade 11

MoNE based on application criteria (e.g., at least 3 years of experience). In addition, they are scored and lined up by considering their graduate degrees, academic publications, projects, congress presentations and student project consultancy (MoNE, 2026; 2019). Then, teachers with the highest scores are interviewed and then selected ones are appointed to the SACs (MoNE, 2026).

This current study selected conveniently a SAC located in the East Black Sea region of Türkiye. The research process consisted of three parts (Fig. 1). The first part included an implementation of a training program for the teachers. The second part focused on SSICCs exhibitions in the school corridors by alternating every 2 weeks. In the third part, the students participated in in-class dialogic discussions concerning SSICCs that were exhibited simultaneously (Fig. 2). To ensure the validity of SSICCs, the researchers developed and validated a rubric to address content and construct validity of the concept cartoons from two main headings: structural features (the problem presentation, use of language, attractiveness, organization and visual design) and the argumentative features in the SSI (the relationship of the dialogues with SSI and their reflection of the discussion components) (see Atasoy et al. (2022) for further detailed information about development and validation of SSICCs).

The teachers attended a 16-h teacher training program as part of a research project that focused on developing teachers' pedagogical knowledge about using concept cartoons in dialogic discussions in the context of SSI. The project was supported by The Scientific and Technological Research Council in Türkiye and conducted by the researchers of this study (TÜBİTAK, Project No:117K137). The training program was held over 2 days. All the researchers of this study actively were involved as the instructors in the program.

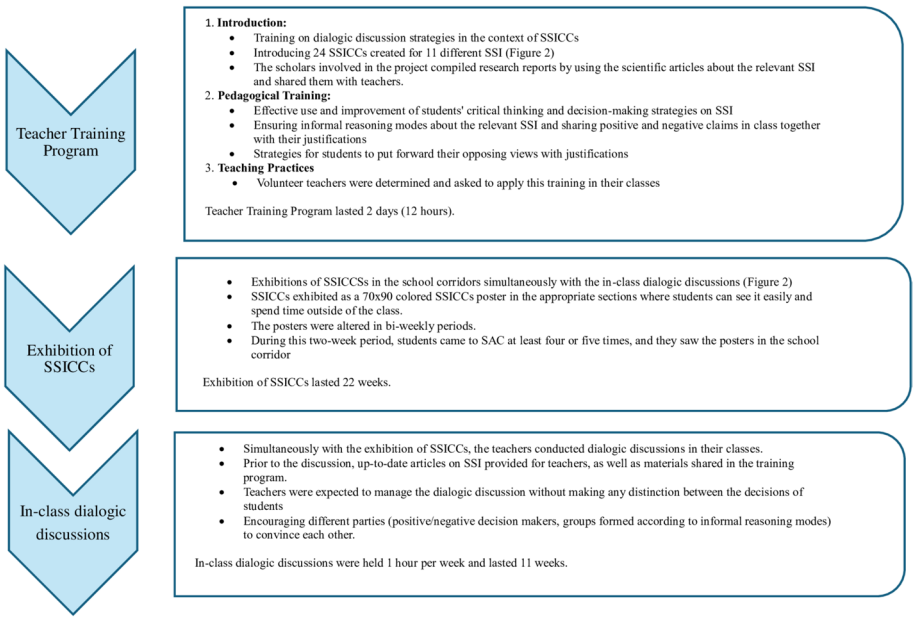


Fig. 1 The research process of the study

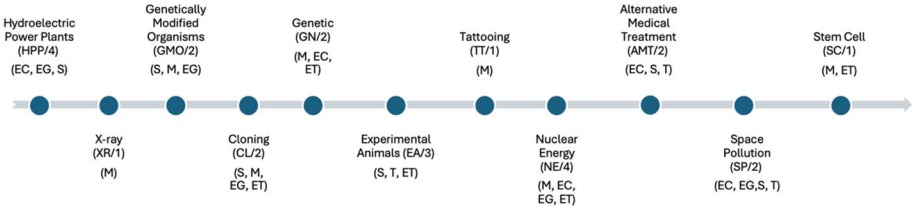


Fig. 2 Exhibition order of SSICCs (abbreviation/number) according to subjects and the informal reasoning modes included in SSICCs (informal reasoning modes in conversation texts of concept cartoons: EC: economic; EG: ecological; S: social; M: medical; ET: ethical; T: technological)

To curate SSICCs exhibition (Fig. 2), the teachers' opinions were taken to identify topics that would resonate with the gifted students' interest and pose intellectual challenges by linking their learned concepts to real-world applications. The authors also consulted the teachers to determine the informal reasoning modes displayed in the concept cartoons (for example, hydroelectrical power plants (HPP): economic, ecological, and social) and disciplinary diversity (such as physics, chemistry, biology, and astronomy). The projects and studies produced by students at SAC and the life stories of different scientists are routinely exhibited in the SAC corridors as posters or visuals to inform and attract the gifted students' attention. For this reason, this study also displayed SSICCs in the corridors to gain the students' attention to SSI before discussing them in class.

During in-class dialogic discussions, video-recordings were taken and watched periodically (by two researchers). The situations that needed to be improved in the discussion process were determined (such as monotony of the discussion environment, and teacher-centered behaviors) and feedback meetings were held with the teachers (see Fig. 3). As seen from Fig. 3, the teachers were guided continuously to encourage their students to discuss SSI from multiple disciplines. Throughout each feedback meetings, the teachers were reminded to use research reports, which were compiled by the researchers of this study for

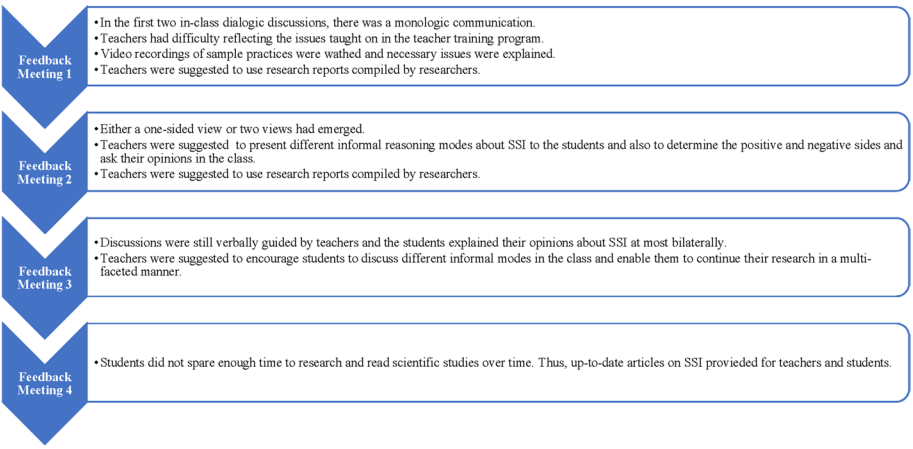


Fig. 3 The process of feedback meetings

each SSI and shared with the teachers during the teacher training program. The researchers also provided up-to-date articles on SSI to the teachers.

3.3 Data Collection Instruments and Analysis

To address the research questions, two data collection instruments (DIT Observation Scale and Interview Protocols) were used. Table 2 outlines data collection and analysis methods regarding each research question.

3.3.1 DIT Observations Scale

This study deployed the Dialogic Inquiry Tool (DIT) to address RQ1. This observation scale was originally developed by Reznitskaya (2012) and later adapted into Turkish by Turhan and Kılınç (2021). Each teacher's in-class dialogic discussions about SSICCs were video-recorded and observed by using the DIT. The indicators in the DIT reflect different situations about teacher-student interaction in the classroom (power relations, clarity of questions, meaningful feedback, encouraging students to reflect and elaborate on their thinking, and engaging in the co-construction of knowledge) (Reznitskaya, 2012). Each teacher's 11 lesson plans (a total of 33 lesson observations–45 min for each lesson) were observed via the observation scales and video recordings. Three researchers took part in the lesson observations and at least two of them rotationally observed the lessons to negotiate any disagreement or un-overlapped scores/notes.

3.3.2 Analysis of Data Obtained from the DIT Observation Scale

Each teacher's in-class dialogic discussions were observed and scored by the researchers. After the observations were completed, a second researcher watched the video recordings and scored them again. The inter-rater consistency value was 92%, which means a high agreement. A third researcher was invited to discuss and negotiate the inconsistent encodings/observations. By doing this, they tried to reach an absolute consensus. The data from the DIT observation scale were analyzed by using the indicators—authority, questions, feedback, meta-level reflection: connecting student ideas, explanation, and collaboration (Reznitskaya, 2012). These indicators include several key behaviors in the context of teacher-student interaction: for example, how does the teacher behave, ask questions and give feedback to increase student engagement? How do students participate in discussions, consider different views and express their opinions? The reflection of teacher-student interaction in dialogic discussion can occur at six dialogic discussion levels: strong monologic (SM), weak monologic (WM), weak semi-dialogic (WSD), strong semi-dialogic (SSD), weak dialogic (WD), and strong dialogic (SD). Table 3 illustrates how the various aspects of in-class discussions (called classroom communication) were weighted and combined into the categories ranging from strong monologic (the most monologic) to strong dialogic (the most dialogic).

These levels were also scored: SM = 1 point, WM = 2 points, WSD = 3 points, SSD = 4 points, WD = 5 points, and SD = 6 points (this scale indicates that the scores increase from the most monologic to the most dialogic). Using these scoring, the graph showing the weekly in-class dialogic discussion level for each teacher was created according to the

Table 2 Data collection and analysis methods corresponding to each research question (RQ)

Research questions	The data collection tools	The analysis methods
RQ1	The DIT observation scale was employed to address the teachers' dialogic discussions (e.g., indicators of authority, questions, feedback, meta-level reflection: connecting student ideas, explanation, and collaboration)	Dialogic discussion was classified as strong monologic (SM), weak monologic (WM), weak semi-dialogic (WSD), strong semi-dialogic (SSD), weak dialogic (WD), and strong dialogic (SD) according to the extent to which the teachers reflected the indicators
RQ2	The interview protocols used to obtain the gifted students' decision making competences (questions with SSI scenario and open-ended questions)	The gifted students' decision-making competences were analyzed as spontaneous level, low level of metareflection, intermediate level of metareflection and high level of metareflection
RQ3	The interview protocols used to obtain the gifted students' informal reasoning modes (questions with SSI scenario and open-ended questions)	The gifted students' informal reasoning modes were labelled as economic, ecological, medical, ethical, technological and social

Table 3 Categories and definitions of the teachers' in-class dialogic discussions in regard to Reznitskaya's (2012) observation scale

Dialogic discussion levels		
Categories levels		Definitions
Monologic	Strong	The teacher has full control over discussion content and processes. Students are positioned as "passive recipients," and only listen the teacher
	Weak	The teacher has mostly control over the content and processes of discussion. Students do not interact with each other; but they answer questions posed by the teacher. Later, the teacher verifies their answers and continues his/her explanation
Semi-dialogic	Weak	Although the teacher possesses a significant degree of control, he/she can somewhat encourage students to participate in the learning tasks or activities or allow them to have some flexibility regarding turn-taking. Even if students do not directly interact with each other, one student's comment influences another student's idea. Their interactions help them develop explanations together
	Strong	Although the teacher posseses a significant degree of control, they can somewhat encourage students to better participate in the learning tasks or activities or allow them to have greater flexibility in turn-taking. Without interrupting any comment, the teacher allows several students to speak in turn. Students offer different evidence and perspectives to enrich their peers' talks/views
Dialogic	Weak	The teacher asks questions (e.g., "Why do you think that?" and "Do you agree with your friend's opinion?") to stimulate their talks. Students somewhat talk to each other, ask questions, and scientifically inquiry any unclear issue in their peers' arguments
	Strong	The teacher acts as a "facilitator" role rather than an authority telling the truth. The teacher only intervenes when the discussion pauses at an impasse or needs a new perspective. In this process, he/she ask such questions as "Well, what can we say about X in this case?" and "Do you have any other evidence?" Students directly interact with each other, ask questions to their peers, and respond to their claims

average scores for each indicator. The levels were interpreted with the following ranges: 1–1.82 (SM level), 1.83–2.65 (WM level), 2.66–3.48 (WSD level), 3.49–4.31 (SSD level), 4.32–5.15 (WD level) and 5.16–6.0 (SD level).

3.3.3 Interview Protocols

Interview protocols developed and validated by Atasoy et al. (2022) for 11 different SSI were used to collect data to determine the gifted students' decision-making competences (RQ2) and informal reasoning modes about SSI (RQ3) before and after in-class dialogic discussions. Each interview protocol included the scenario about the SSI and open-ended questions to determine the gifted students' thoughts about the situations in the scenario. The content validity of the protocols was ensured with the expert opinions (one science educator, one biology educator, and one physics educator). A pilot study was conducted with two high school gifted students. Based on the experts' feedback and the findings of the pilot study, positive and negative explanations in the scenarios and the structure of the questions were revised (see Supplementary Material for a sample interview protocol). Each interview session was conducted with one-to-one (individually) basis and lasted approximately 25–35 min. Eight of the high school gifted students participated in the pre- and post-interviews, while one was absent frequently and did not attend the post-interview. The interviews were tape-recorded and then all of them were transcribed verbatim.

3.3.4 Analysis of the Data from Interviews

Interview data were subjected to descriptive analysis to reveal students' decision-making competences and informal reasoning modes. That is, descriptive analysis was used to classify the data according to previously created thematic framework (Creswell, 2007). Students' decision-making competences regarding SSI were analyzed by using Eggert and Bögeholz's (2010) classification while informal reasoning modes were handled in the light of Wu and Tsai's (2011) study. Each descriptive analysis was detailed in the following.

Analysis of the Gifted Students' Decision-Making Competences This study adapted Eggert and Bögeholz's (2010) classification model for decision-making strategies to analyze the gifted students' decision-making competences about SSI. Namely, the use of and reflection on decision-making strategies consisted of the subsequent classification: spontaneous level, low level of metareflection, intermediate level of metareflection and high level of metareflection (Table 4). To ensure the reliability of the data analysis, two researchers separately analyzed the dataset. The inter-rater consistency value was calculated 82%. Table 4 illustrates the analysis procedure with the quotations from the study.

Analysis of the Gifted Students' Informal Reasoning Modes The data from the interviews were descriptively categorized according to informal reasoning modes, which are similar to Wu and Tsai's (2011) ones (see Table 5 for informal reasoning modes). Along with these, medical and ethical dimensions emerged in this study. Informal reasoning modes adapted from Atasoy (2018) are presented in Table 5.

Table 4 Decision-making competences about SSI adapted from Eggert and Bögeholz's (2010, p. 235) model

Decision-making competence levels	Explanation	Example expressions of HPP
Spontaneous	Includes emotional, intuitive decision-making; but lacks reasoning and compromise	"…there is an increase in electricity. It would be very beneficial for that area… Yes, it changes nature in every sense."
Low level of metareflection	Includes noncompensatory decision-making strategy (use of cutoffs) and lacks compromise	"Our country depends on other countries for energy supply. So we need to find a better solution in producing energy…we need to find a less harmful solution or we will continue to use HPPs. I personally think that human beings should not harm nature, but we have difficulty in preventing it…but we have no chance to overcome technological problems. Energy will make us powerful. That's why I think energy is necessary."
Intermediate level of metareflection	Includes mixed strategy between noncompensatory and compensatory decision-making (use of cutoffs and trade-offs)	"..Construction of a HPP can be acceptable, if it is built in a virgin area or in a place where tourism is not very developed,ecologically is not very important and construction of alternative energy sources is not possible. If nature, animals, plants, and populations are not affected,, I am in favor of building a few HPPs and reducing the number of already existing HPPs as the energy demand decreases. As I said, HPP construction is currently necessary for the country's energy demand. However, it should be ensured that they are in compliance with environmental conditions and that people, nature and other living things are not affected. After all, the country needs this."
High level of metareflection	Includes compensatory decision-making strategy (use of trade-offs) by explicitly weighing/comparing of criteria of trade-offs within multiple perspectives	"I think there are better energy sources, like solar energy, nuclear power plants… So it should be increased, but not too much …It may have a negative impact on the living things in that river or the living things that meet their water needs from that water source. For example, the fish population living in that river t may decrease and there may be deaths of the living things that get their water from there. Or it may have negative impacts on people who use water and do agriculture in that region. As a positive effect, we can produce energy because we also need energy. It would also create job opportunities for the people working there. It would also reduce unemployment in a way …As I said, I think we need to use other sources of energy. It would be less harmful to the living things living in these areas. I mean, I look at it from an environmental point of view."

Table 5 Codes and quotations indicating informal reasoning modes

Informal reasoning modes (abbreviations)	Codes	Example statements and codes
Economic (EC)	Cheapness/expensiveness in production/consumption Amount of income Amount of product Tourism income	The construction of the HPP should continue because it can produce electricity cheaply (Code: cheapness/expensiveness in production/consumption)
Ecological (EG)	Surrounding plants and animals Natural beauty Environmental degradation	HPP are one of the most environmentally friendly ways to meet the increasing energy demand… (Code: natural beauty)
Technological (T)	Technological development Scientific knowledge	…HPP must exist. Because today, electricity is generally required to use technological devices. This way, technology will develop further… (Code: technological development)
Social (S)	Community/country benefits and interests Community/human health Human relations	…Thanks to HPP, we can generate our own electricity and thus avoid dependence on foreign sources… (Code: community/country benefits and interests)
Medical (M)	Human health, medical risks, quality of life and physical/mental integrity	Disruption of the natural flow of water sources used by the local population can reduce water's self-purification capacity, compromising drinking water quality and leading to gastrointestinal diseases. (Codes: human health and medical risks)
Ethical (ET)	Justice, animal rights, responsibility for future generations	…That river is not just a water source; it is also home to endemic fish species, and it is not within our authority to destroy their habitats. (Code: animal rights)

To ensure the reliability of the data analysis, two researchers separately analyzed them. The inter-rater consistency was computed 84%. Any disagreement was resolved by asking the opinions of the third and fourth researchers. Hence, they intended to reach a joint (consensus) decision.

4 Results

This section analyzes the dialogic discussions conducted in different SSICCs and examines how these discussions in the classes of the three teachers influenced students' decision-making competences and informal reasoning modes about SSI.

4.1 Results Related to RQ1: SAC Teachers' Dialogic Discussions

The average scores of the teachers' dialogic discussions according to the DIT are presented in Fig. 4. The figure also shows the weekly changes in the teachers' dialogic levels. According to Fig. 4, teachers Nehir, Ela, and Murat displayed different levels of dialogic discussions for each SSICCs (SSICCs were discussed in the same order weekly in classes). Given the teachers' weekly in-class dialogic performances, the first 2 weeks were categorized under the WM-SSD levels. In Week 3, Nehir and Ela reached the WD level, and in Week 4, all teachers reached the WD level. In Week 5, Nehir's class remained at the WD level, while Ela's and Murat's classes were at a lower level. Starting from Week 6, teacher Nehir conducted discussions at the SSD level for only 2 weeks. In other weeks (7, 8, 10, 11), she was at the WD level. Although the topics varied, she maintained a consistent level in conducting dialogic discussions.

Teacher Nehir performed WM dialogic discussion for the first 2 weeks for HPP and XR. She deployed the following provocative question to guide her discussion at the WM level on HPP:

> Teacher Nehir: So, does it matter whether the water is salty or fresh for an HPP? Do you think it is important for an HPP?
> Student 5: I do not think it matters.



Fig. 4 Average scores of teachers' weekly dialogic discussions (HPP: hydroelectric power plants; XR: X-ray; GMO: genetically modified organisms; CL: cloning; GN: genetic; EA; experimental animals; TT: tattooing; NE: nuclear energy; AMT: alternative medical treatment; SP: space pollution; SC: stem cell)

Teacher Nehir: So the amount of salt does not affect the potential energy of the water, right?

She directly asked questions to the students and had a great deal of control over discussions on the content and process. She also showed progress in the dialogic discussion by Week 3 and generally taught at the WD level for GMO, CL, GN, TT, NE, and SP. The discussions in Weeks 6 and 9 were a little bit lover from the WD level. For discussions at the WD level, she used the provocative questions to guide her discussion. The excerpt below, taken from the GN discussion, reveals that she tried to help the students discover more by working on their answers. For example, by asking "Well, why do you think it is objectionable?" she was moving the student away from a simple "yes/no" answer and challenging them to reason. The dialogue continued with a follow-up question based on the student's answer.

Teacher Nehir: You say that the cow will produce more milk if it is genetically modified, so why do you think this is objectionable?
Student 4: Productivity increases, but milk quality decreases. It is an unnatural intervention after all; we do not know if people who drink this milk will get cancer in the future.
Teacher Nehir: Well, does anyone else see another risk? Is it only human health that is affected?
Student 6: I think not only humans, but the cow itself will be harmed. Forcing the animal to produce more milk than its capacity will exhaust its body and disrupt its biological balance.

In the dialogue, students built on each other's ideas by discussing both human health and animal welfare through peer discussion.

Teacher Ela conducted relatively dialogic discussions and mostly stayed at the SSD level throughout teaching weeks. In Weeks 3, 4, and 9 including the biology-based topics of GMO, CL, and AMT, dialogic discussions were held at the WD level. The other weeks, except for Weeks 1 and 7, the teachers' levels of dialogic discussions were relatively less fluctuating and stayed at the SSD level. Since teacher Ela's research interests covered biotechnology and biochemistry, conducted discussions at the SSD level for XR, GN, EA, NE, SP, and SC; and the WD level for GMO, Cl, and AMT (Fig. 4).

The subsequent provocative question about XR exemplifies her discussion in the SSD level:

Teacher Ela: So what can we say? Okay, good imaging technique allows us to make a diagnosis. It is helpful, but is it used in a controlled manner, or arbitrarily?
Student 3: It needs to be controlled. If we go in too much, we could be harmed.

As shown in the above questioning pattern, Teacher Ela listened to the student's answer and asked the provocative question based on this answer to refine it to two options. Therefore, students missed the opportunity to advance the discussion. She performed her highest dialogic discussions for GMO, CL, and AMT. A provocative question about GMO guided her discussion as follows:

Teacher Ela: One of you said that chemicals are harmful; we do not have to be exposed to GMO because they are less harmful. Another stated that we do not have to use chemicals; organic farming can use conventional seeds. So, they said, we are not doomed to GMO.

This excerpt showed that the teacher tried to make connections between her students' ideas. Teacher Ela held the WSD level discussions in Weeks 1 (HPP) and 7 (TT). Observing the WSD level in Week 1 is acceptable due to being the first class implementation. However, in Week 7, repeating the WSD level could be related to the context of SSI. For example, she asked the following questions about TT to guide the class discussion:

> Teacher Ela: I wonder if these tattoos give a message to anyone. Is there such a perception when you see them?
> Student 1: Well... yes, I think it might be sending a message...

As seen from the questions, she was weak in raising reflective questions to challenge the students' thinking. Moreover, she did not allow her student to respond to the question or think of the next question by asking questions back-to-back. She attempted to confirm the first question with the next one. The student also approved the teacher.

Although Teacher Murat experienced an unusual decline in Week 5, when discussions on GN were carried out, his approach shifted in subsequent weeks. He conducted more consistent discussions at the SD level in Weeks 6, 7, and 8. However, in the last 3 weeks, his level of dialogic discussion decreased to the SSD level, and in Week 11, he completed the process at the WSD level. Compared to others, Teacher Murat's level of dialogic discussion showed less improvement with the highest fluctuations among dialogic discussion levels (WM, WSD, SSD, WD, and SD). Since his major was in physics, his limited content knowledge of or being less familiar with biology concepts might be the reason of these fluctuations.

He exhibited the lowest dialogic discussion in Weeks 1 (HPP) and 5 (GN). Like all teachers, observing the lowest level of discussion in the first week is acceptable. However, observing the WM level for Week 5 might be related to requirement to use more genetic concepts in discussion. For example, he used the following excerpt to guide his discussion on GN:

> Teacher Murat: Imagine that I do not eat organic products and live in the same environment as you. This will harm you too... So, what I am trying to say is this: We get fruits from my grandmother and milk from my grandfather. But we breathe the same air together. So, if I eat something harmful, it will infect you too.

This excerpt showed that he had much control over both the content by using general information and the process of the discussion about GN.

In-class dialogic discussions in Weeks 6, 7, and 8, he reached the highest level of dialogic discussion among all teachers regarding EA, TT, and NE. Especially with the physics related topic he performed his highest level of dialogic discussions. The following provocative question represents how he guided his discussion for NE:

> Teacher Murat: So where can nuclear power plants be built to reduce environmental risks? Can they be built in the middle of the steppe? Can the necessary technology be produced for a power plant that does not require irrigation? How?
> Student 8: If we build it in the desert, we will need to use underground water. That would hurt farming and the environment nearby. We could make cooling systems that use large fans, like car fans, instead of water. But air does not cool as well as water, so these systems would need to be much bigger and cost more.
> Student 9: I also think we need to develop alternative cooling systems instead of water. For example, we could build reactors that use gases such as helium or car-

bon dioxide. If the gases spin the turbine directly, rather than boiling water, I think they would be more efficient and use less water.

Through these questions, Teacher Murat encouraged his students to employ higher-order thinking skills and engage in critical evaluation and analysis of the NE case. The students listened to each other and developed each other's ideas to solve the NE case while generating alternative ideas.

4.2 Results Related to RQ2: Gifted Students' Decision-Making Competences

The students' decision-making competences in the teachers' classes before and after in-class dialogic discussions with SSICCs are given in Fig. 5. As seen in Fig. 5, the pre-interview findings revealed that the three teachers' students generally decided at a spontaneous decision-making level and low metareflection, and few students decided at an intermediate metareflection. None of the students decided at a high metareflection in the pre-interview. While the number of students, who decided at the spontaneous level, decreased in the post-interview, they could choose mainly at the intermediate level of metareflection. Some students (one each for HPP, CL, GN, EA, NE, and AMT and two for SP) of Murat and Nehir (one for NE) could decide at the high level, while Ela's students failed it.

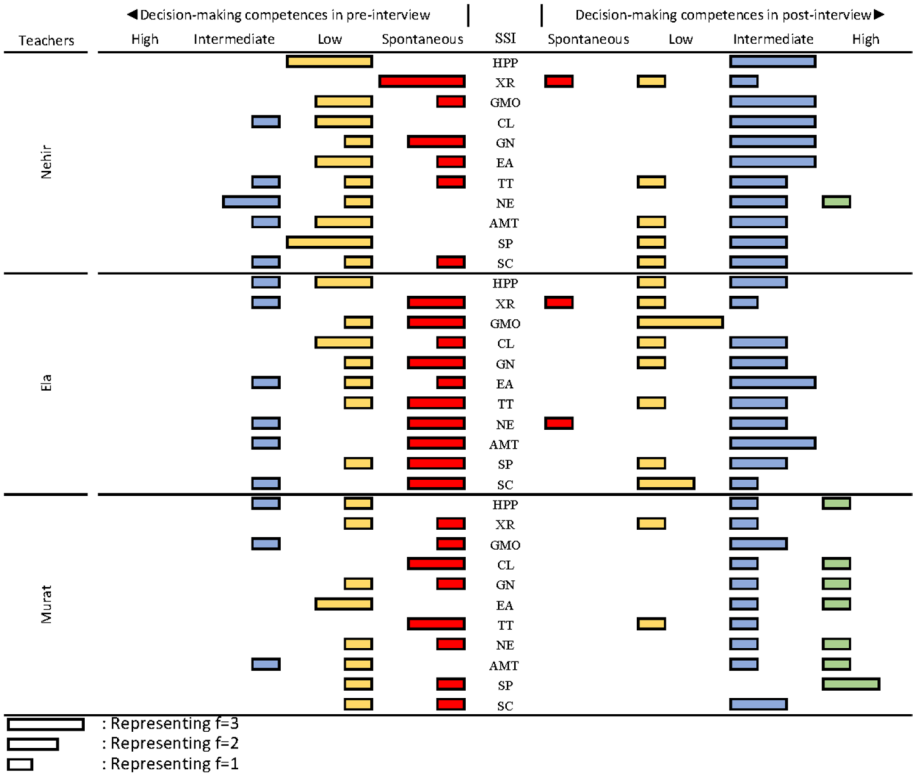


Fig. 5 Distribution of decision-making competences of the students in the teachers' classes according to SSI in the pre- and post-interviews

While Teacher Nehir discussed at the WM level (in HPP and XR), her students' decision-making competences regarding HPP progressed from a low level of metareflection to an intermediate level. In contrast, the pre-interviews revealed that her students were at the spontaneous level for XR; however, the post-interviews showed that one remained at the same level, while two of them moved up to advanced metareflection levels (one each for low and intermediate). The following sample quotations illustrate how the students' advanced decision-making competences for HPP progressed from low to intermediate level:

> Student 6: HPPs should be increased, renewable energy sources. Foreign dependency should be minimized. Here, he talks about dumping waste into streams (mentioned in the interview scenario)...This should not be done haphazardly; living things should be considered. (pre-interview, low level of metareflection)
> Student 6: I think yes, it should be increased, but it should be increased in a controlled manner. Because our energy needs are very high, and we constantly depend on external sources...It harms living things. It may endanger the habitat of fish or creatures. These aside, as a country on, this issue, we are externally dependent. So, the number of HPPs should be increased. (post-interview, intermediate level of metareflection)

In the pre-interview, this student decided that HPP should be continued without making any shortcuts or compromises, eliminating options such as HPP being a renewable energy source, its adverse environmental effects, and foreign dependency on energy (as mentioned in the interview scenario). In the post-interview, it was seen that the same student evaluated the issue from different aspects but made a compromise of minimizing its impact on the environment when making his final decision. He made concessions after eliminating the option of continuing or not continuing regarding the HPP.

While Teacher Nehir implemented dialogical discussion at the WD level, her students' decision-making competences generally progressed from the low level to the intermediate level of metareflection. In the pre-interview, one student in GMO and TT and two in GN were at the spontaneous level. In the post-interview, only one student was at the spontaneous level in XR. In the post-interview, one student was at a low level in TT and SP, one advanced at a high level in NE (her highest dialogic discussion), and one evolved to an intermediate level of metareflection. Some students made spontaneous, low, and intermediate level of metareflection decisions in the pre-interview for EA, AMT, and SC. At the post-interview, it was seen that two of these students were at a low level, while one performed at the intermediate level. Generally, while most of her students showed a low level of metareflection in the pre-interviews, their decision-making competences mostly fell into the intermediate level of metareflection in the post-interviews.

Teacher Ela's students showed no improvement in their decision-making competences regarding HPP, where she had the WSD level for her discussions. However, the students, who made spontaneous decisions about TT in the pre-interviews, did not use them in the post-interviews. One student in each of two SSI (HPP and TT) was at the low level, while two were at the intermediate level (one student's decision-making competence was the same for HPP in the pre- and post-interview).

The spontaneous decision-making level contained two students each for SSI, except for one student on EA, in the pre-interviews and one student each in physics topics such as XR and NE. The number of the students reaching the intermediate level of metareflection in biology topics such as GN and EA was higher. Sample quotations of EA are shown in the following to illustrate an advanced decision-making competence from spontaneous to intermediate level:

> Student 2:...I cannot tolerate the suffering of animals. I am an animal lover. I cannot stand such things... I absolutely do not support the use of animals in experiments. I think it should be banned... (pre-interview, spontaneous decision-making level)
> Student 2: I would not want drugs to be used on myself… Scientific and more accurate information can be obtained by using guinea pigs. Negatively, a living being's life may be in danger. Logically, it is correct to use guinea pigs. However, they should not be used if they will be damaged. Maybe if one day I get very helpless and get sick. (post-interview, intermediate level of metareflection)

In the pre-interview, Student 2 explained his decision regarding EA with emotional reasons and did not use trade-offs. In the post-interview, he accepted the use of EA and made a comparison but offered certain conditions or pre-requests. For example, the pre-request or condition was that the animals would not be harmed as a compromise. In the post-interviews, GMO, CL, and AMT did not include any spontaneous decisions, while all students had a low level of metareflection in GMO and an intermediate level of metareflection in AMT. While one student remained at the low level in CL, two increased to the intermediate level.

For Teacher Murat's students, their decision-making competences of HPP and GN were classified under intermediate and high levels of metareflection, respectively. The students' decision-making competences also increased in EA, TT, and NE along with high-level discussions (Fig. 5). They reached intermediate and high levels in EA and NE, while their decision-making competences evolved from a spontaneous level at the pre-interviews to low and intermediate ones in the post-interviews.

The students' decision-making levels of XR and AMT slightly increased, while their competences of SP progressed from spontaneous and low levels to a high level. Quotations are shown to illustrate an advanced decision-making competence from spontaneous to high level in SP:

> Student 7: Most likely, what our country sends will cause SP. If I look at it from our perspective, we do not do the job properly… (spontaneous decision-making level, pre-interview)
> Student 7:...All communication tools work based on this. That's why it should be sent. It also allows us to advance in communication and technology. It allows us to produce our technological tools. Improving our technology also enables us to become stronger against other states. First, the satellites sent can be more resistant to impacts. Work can be done to clean up space debris. Space garbage hits something. As a result, thousands more space debris is created. Satellites can no longer be sent due to space pollution. (high level of metareflection, post-interview)

During the pre-interview, Student 7 made a spontaneous decision to blame himself for space garbage. In the post-interview, he discussed the benefits of launching more satellites into space and possible solutions to pollution, weighing the pros and cons of SP. Because of his use of the trade-off (e.g., more satellites would cause space debris), he made a high level of metareflection. Spontaneous decisions of GMO and SC included one student each in the pre-interviews. These decisions disappeared in the post-interviews. The students' post-decision-making competences had advanced to the intermediate level of metareflection while one student possessed a stable metareflection for GMO.

4.3 Results Related to RQ3: Gifted Students' Informal Reasoning Modes

The students' informal reasoning modes before and after in-class dialogic discussions with each SSICCs are presented in Fig. 6, organized by the number of students (f). Figure 6

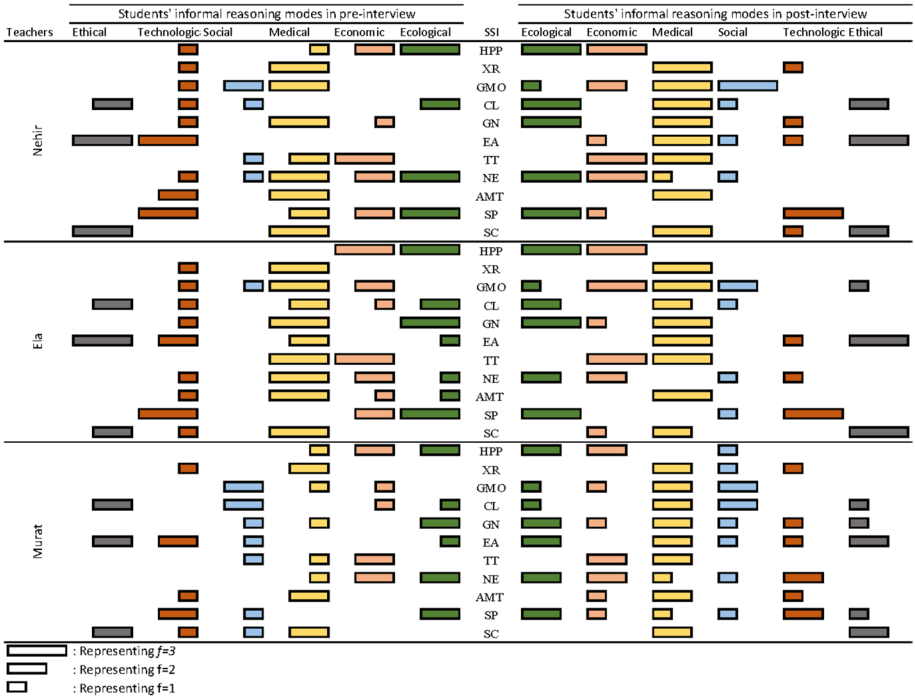


Fig. 6 Distribution of informal reasoning modes of the students in the teachers' classes according to SSI in the pre- and post-interviews

shows that students used different reasoning modes depending on the subject when making decisions regarding SSI. Also, they exploited more than one reasoning mode when deciding on an issue. This is consistent with the inclusion of various reasoning modes in the design of SSICCs (see Fig. 2). Additionally, the students of different teachers employed various modes at different frequencies. It was seen that the teachers influenced the diversity in the students' use of modes.

Students' informal reasoning modes of XR (technologic and medical) did not change after the dialogic discussions in Teacher Nehir's class. In contrast, their informal reasoning modes of HPP shifted. That is, while four types (technologic, medical, economic, and ecological) were noted in the pre-interview, only two (ecological and economic) were present in the post-interview. Furthermore, the findings of the post-interview incorporated new modes (ecological and medical reasoning) in discussions of GMO, CL, and GN. Some excerpts are given below:

> Student 6: …we already have a large population, and for this reason, both as a country and as a world, I would not want to produce more living things (social mode). (pre-interview)
> Student 6: I would not clone it. Because the idea of having another one like me in the world does not sound good to me...Every person has a side of themselves that they do not like (social mode)...I would use it for endangered animals (ecological mode). So, it should be used in a critical situation. For example, cloning could produce bio-artificial organs (medical mode). (post-interview)

Student 6 used social reasoning regarding CL in the pre-interview and added ecological and medical modes in the post-interview. The students of teacher Nehir developed explanations about EA in ethical and technological modes in the pre-interviews and economic, medical, and social modes in the post-interviews. While there were explanations based on technological and medical modes in the pre-interviews regarding AMT, the post-interview only contained a medical mode. The students developed their own explanations from ethical modes at the pre- and post-interviews for the EA and SCs. The same number of students applied to the medical mode in three SSI in the pre- (except for EA) and post-interviews.

The students of Teacher Ela, who made decisions about HPP by developing economic and ecological informal reasoning modes in the pre-interviews, used the same reasoning modes in the post-interviews (Fig. 6). A similar reasoning mode (economic and medical modes) was also observed for the pre- and post-interviews of TT.

> Student 3: After all, tattoos are made of chemicals, which may cause side effects on our body (medical mode) … Additionally, since those skin pores are closed, the skin there will not behave normally, and health problems may occur (medical mode). (pre-interview)
> Student 3: After all, tattoos mix with our blood; I think this will be harmful (medical mode)... I think tattoos that can be removed, that is, do not mix with the blood, should be made, it makes more sense... (post-interview)

His pre-reasoning expression included the harmful effects of TT regarding health, while the post-reasoning suggested alternative ways to prevent health problems that TT may cause. In the pre- and post-interviews, Teacher Ela's students referred to the medical mode for XR and GN and the ecological mode for GN and SP. The number of students using medical statements increased from two to three for EA, while it decreased from three to two for SC. This indicates that the students cited medical mode in explaining their reasoning about all SSI, except for SP. Interestingly, although three of the students handled the medical mode for NE in the pre-interview, they did not use any medical explanations in the post-interviews. They primarily focused on ecological and social modes. Additionally, the students developed ethical explanations for EA and SC, incorporating biology topics/concepts.

The variety of informal reasoning modes decreased from the pre-interviews to the post-ones (Fig. 6). Medical mode remained the same for all SSI. While the pre-interviews contained technological mode for XR, GMO, CL, GN and AMT and an ethical mode for CL, they disappeared in the post-interviews.

For the students of Teacher Murat, while there was no change in their reasoning modes regarding HPP, their post-interviews of GN included all modes. Thus, the diversity of reasoning modes increased. A similar case was also valid for EA, in which the students added medical mode. Quotations of Student 9's pre- and post-explanations are shown as follows:

> Student 9:...because energy is something that has a high cost (economic mode) and since there are no energy resources such as natural gas in our country, I think it is necessary to build such reactors…the lands, where the farmers produce, will become infertile, and the living environment of the person will become even worse (ecological mode). (pre-interview)
> Student 9:...nuclear power plants may have health risks, so it would be more logical to build them where there are no people (health mode)... When large facilities are built in the city center, more important things can be done there; for example, you may be occupying the area of a hospital (social mode)... There will always be human errors. One way to prevent this is to automate everything (technological mode)... I

have seen that it is two or two and a half times more efficient than sources such as NE, Solar energy, and wind turbines (economic mode)... (post-interview)

In the pre-interview, he had a positive view on NE to reduce energy costs and a negative view about its harmful effects on the environment. Thereby, economic and ecological modes emerged. In the post-interview, he used medical and social modes by stating that nuclear power plants can be built in areas where people do not live in terms of human health and social needs. Proposing an automation system to prevent the dangers of NE was evaluated as an ecological mode. In addition, his post-statement on higher efficiency of NE appeared an economic mode.

His students' informal reasoning modes of XR and AMT did not show any change. However, their explanations of SP covered ecological, social, and technological reasoning modes in the pre-interviews, and economic, medical, and ethical modes in the post-interviews. In the post-interviews, his students used more reasoning modes of GMO. In contrast, their reasoning modes of SC refined from the pre-interviews (medical, social, technological, and ethical) to the post-ones (medical and ethical).

5 Discussion

This section discusses the findings of the current study regarding the research questions.

5.1 The Dialogic Level of SAC Teachers' Dialogic Discussions Using SSICCS for the Gifted Students (RQ1)

As seen from Fig. 4, the high school teachers' dialogic discussions fell into the WM and WSD levels during the first 2 weeks of the dialogic discussion. Even though they were practically trained about the implementation of the dialogic discussion and naturally had high in-class interactions with the small number of the gifted students in their classes, this was the first time they had initially conducted it with their own students. Thereby, the teachers' pre-existing experiences (e.g., talk and conversation instead of dialogic discussion) may have influenced their preferences for the dialogic discussion in their classes (Yildirim et al., 2023). Moreover, the first 2 weeks seem to have acted as a habituation phase. As a matter of fact, HPP as the first topic of the dialogic discussion may have served as a warm-up activity since they had the lowest dialogic level for HPP. Afterwards, their discussions were improved to the SSD and WD levels, whereas they performed the SSD level for the last 3 weeks. This finding indicates that an increase in the teachers' familiarity with the dialogic discussion seems to have improved their dialogic discussions in practicum. Indeed, this may result from the feedback meetings promoting the teachers to re-think about their dialogic discussions. This highlights the framework of feedback meetings in the current research process, which may remarkably contribute to a more productive discussion environment in the teachers' classrooms. Thereby, such an effort seems to have made their dialogic discussions sustainable and challenged their pre-existing habits (e.g., monologic) (Kilinc et al., 2017). This finding suggests that the teacher training program has not only enhanced their knowledge and skills of the dialogic discussion but also assisted them into realizing the notion or nature of "class dialogue" (e.g., elaboration, querying and student participation) (Hennessy et al., 2023; Howe et al., 2019; Mercer, 1995) to some extent.

This also supports Hennessy et al.'s (2023) argument about the role of dialogic discussions on productive learning and guiding construction of knowledge.

Their dialogic discussions between the first 2 weeks and the last 3 weeks may be viewed as a balance preference between their pre-existing habits and targeted ones (Atasoy et al., 2022; Scott et al., 2006). As a matter of fact, their discussions classified under the SSD level at the last 3 weeks support Martin and Hand's (2009) idea that a transition from monologic level to dialogic one takes a long time and is a tough process. This also advocates Howe et al.'s (2019) view that dialogic pedagogy or ethos needs a longer time to typically set up fundamental characteristics (e.g., open-mindedness, reduced role division, and space to explore) or challenge pre-existing habits (e.g., closed-mindedness and increased teacher role). Their familiarity with SSI and SSI-related content knowledge seems to have influenced their dialogic discussions/levels (e.g., Cetin et al., 2014; Newton & Newton, 2001; Sadler & Zeidler, 2005). For example, teacher Nehir, who has been familiar with integrated science teaching due to her graduated program (science teacher education), showed more consistent dialogic discussions than Ela and Murat, who graduated from biology teacher education and physics teacher education respectively. Moreover, their science backgrounds (physics, biology, and science), which may result in variations in content knowledge, may have played a significant role in their in-class dialogic discussions (e.g., Cetin et al., 2014; Newton & Newton, 2001; Sadler & Zeidler, 2005). For instance, teacher Murat's dialogic discussions of GN and SC may result from his limited content knowledge of or familiarity with biology concepts. Similarly, the fact that teacher Ela had the lowest dialogic discussions at HPP and TT may be explained with her biology background that includes limited content knowledge or familiarity with physics and chemistry concepts. Furthermore, only Murat among the teachers achieved a strong dialogic discussion at EA, TT and NE. This may come from his dialogic preference (from monologic to dialogic one) for these SSI and the nature of content knowledge (Kilinc et al., 2017). Nevertheless, the fact that teacher Ela's discussions mostly fell into the WSD and SSD levels may stem from her efforts to find a balance between monologic and dialogic discussions (Atasoy et al., 2022; Scott et al., 2006). Teacher Murat's dialogic performance (five out of six dialogic levels offered by Reznitskaya, 2012) may stem from his limited pedagogical content knowledge (e.g., asking proper questions for activating student-to-student and teacher-to-student interactions through related concepts (Chen & Xiao, 2021; Tidemand & Nielsen, 2017; Zaccarelli et al., 2018).

As compared with Ela's and Murat's dialogic discussions, teacher Nehir showed sustainable and consistent performance along with nearly all SSI. This may stem from her teaching motivation and expectations or beliefs of science teaching. For instance, her students' developing performances in decision-making competences and informal reasoning modes (e.g., elaborating and querying ideas of SSI and making their understanding, reasoning and dialogic learning clear) may have encouraged her to consistently use the dialogic discussion. This is in a harmony with Hennessy et al.'s (2023) statement that teachers in high levels of attainment in dialogue classes are capable of devising numerous successful strategies for encouraging students to join the dialogic discussion and express their agreement(s)/disagreement(s). That is, her successful experiences of its fruitfulness may have shaped her attitudes and beliefs of the dialogic discussions through SSICCs (Guskey, 2002; Zaccarelli et al., 2018). Teacher Nehir's dialogic discussions may be viewed as her effort to create a supportive and open dialogue climate (e.g., querying, elaboration and student participation) that stimulates meaningful, purposeful, and chained interactions between teachers and students (Alexander, 2020; Hennessy et al.,

2023; Howe et al., 2019; Sedova et al., 2016). In fact, this may be viewed as an indicator of a teacher's pedagogical capability of deploying and framing the dialogic discussions, class dialogues or dialogic learning through SSICCs (Howe & Abedin, 2013).

5.2 Gifted Students' Decision-Making Competences After Engaging in Dialogic Discussions Using SSICCs (RQ2)

As seen from Fig. 5, the high school students mostly used spontaneous and low levels of metareflection for decision-making competence before the dialogic discussions. Also, few students recruited the intermediate level of metareflection for decision-making competence. This indicates that regular science teaching activities or materials have deficiencies improving higher-order metareflection levels for decision-making competence (Johnson et al., 1995). In other words, regular science teaching makes little contribution to the development of decision-making competence. This may result from the teachers' dialogic preferences during regular in-class discussion. Also, this may come from a lack of dialogic pedagogy or ethos that typically includes such characteristics as open-mindedness, mutual respect, reduced role division, and space to explore (Howe et al., 2019). This also supports Sedova et al.'s (2016) idea that teachers, who do not attend any in-service or pre-service education on dialogic methods, rarely handle them as part of their inventories of teaching methods.

After the dialogic discussions, frequency of the students categorized under spontaneous level for decision-making competence decreased. Further, their decision-making competence generally fell into the intermediate level of metareflection while a few students achieved high level of metareflection (e.g., some for teacher Murat's class, and one for teacher Nehir's class). This finding suggests that SSICCs enabled them to reconsider their decision-making competences through scientific evidence and discussion (e.g., Atasoy et al., 2022). Namely, the dialogic discussions along with SSICCs may have triggered their higher cognitive functions, thinking and communication skills that develop decision-making competence (Sedova et al., 2016). An improvement in the students' levels of decision-making competence can be also recognized as an indicator of the effectiveness of in-class dialogic discussions. This also points to the framework of the current research process with feedback meetings that asked the teachers to create a more productive discussion environment in their classrooms that stimulate students' decision-making competences. Moreover, the dialogic discussions between the teachers and students, and between the students (peer discussion) seem to have evolved their decision-making competences by producing qualified arguments and employing supportive strategies (Reznitskaya, 2012). In that, the dialogic discussion via SSICCs might have promoted the students to continuously ask the questions "how?" and "why?" while analyzing complex situations in the SSI (Atasoy et al., 2022; Reznitskaya, 2012) and improved their decision-making competences by means of the key features of the dialogic discussion (e.g., elaboration, querying and student participation) (Hennessy et al., 2023; Howe et al., 2019).

It was found that frequencies of high level of metareflection for decision-making competence on SSI were low. This may stem from the teachers' dialogic discussions during in-class activities. For example, teacher Ela's inability to implement any strong dialogic discussion (see Fig. 4) even after the teacher training program and feedback may have restricted her students to accomplish high level of metareflection. In contrast, the relationship between teacher Murat's dialogic discussions (see Fig. 4) and his students' decision-making competences (see Fig. 5) somewhat supports the argument that a teacher's dialogic discussion influences students' decision-making competences about SSI. That is, even though Murat

performed varied levels of dialogic discussion (e.g., WM level for HPP and GN, SSD level for AMT and SP, WD level for CL, and SD level for EA and NE), at least one of his students attained high level of metareflection for decision-making competence. This may be explained with the nature and intrinsic features of gifted students (Cooper et al., 2005; Taber, 2007). Likewise, this may come from their perceptual selectivity or individual interest (e.g., Atasoy et al., 2022; Eggert & Bögeholz, 2010). For instance, even though teacher Murat's research interest did not cover environmental and ecological issues, some of his students performed a high level of metareflection at HPP, CL, GN, EA, NE, AMT and SP. This may stem from the nature or characteristics (e.g., scientific curiosity, cognitive and metacognitive abilities) of gifted students or their environmental and ecological literacy (Cooper et al., 2005; Taber, 2007). On the contrary, teacher Nehir's research interest in ecology and recycling may have influenced her student to capture a high level of metareflection at NE after the dialogic discussion. Interestingly, although teacher Murat's dialogic discussion for TT was labeled under strong dialogic level, his students did not reveal high level of metareflection for decision-making competence. This suggests that a teacher's dialogic discussion, as an extrinsic feature, somewhat affects his/her students' decision-making competences.

The current study had self-contradictions about the role of teachers' tailored science backgrounds on stimulating the students' decision-making competences and implementing the dialogic discussions about SSI (Cetin et al., 2014; Newton & Newton, 2001; Sadler & Zeidler, 2005). For example, although teacher Murat has been working as a physics teacher, his students also performed well at biology-focused SSI (e.g., CL, GN, EA, and AMT). Interestingly, even though teacher Ela has been working as a biology teacher, her students showed low (e.g., GMO, CL, GN, and SC) and intermediate (e.g., CL, GN, EA, and SC) levels of metareflection for biology-focused SSI. This may be interpreted as the complementary role of the teachers' pedagogical skills on encouraging the students' decision-making competences instead of emphasizing teachers' specialized science backgrounds (science, biology and physics), which may engender different disciplinary languages or scientific vocabulary (Zaccarelli et al., 2018). This finding may be also related to the nature of SSI (Atasoy et al., 2022; Kolsto, 2001; Sadler, 2004); students' learning-style differences towards SSI (e.g., Wolfensberger et al., 2010; Yapıcıoğlu & Kaptan, 2017); or teachers' use of different pedagogic styles (Howe & Abedin, 2013). This reveals the importance of teachers' dialogic pedagogies at facing students with different discussion environments according to the characteristics of SSI. Of course, such a dialogic learning environment may have facilitated the development and construction of their decision-making competences and reasoning abilities. In other words, the SSICCs and related dialogic discussions seem to have provided opportunities to the students to "talk science" with each other and their teachers to improve their decision-making competences. These arguments are in harmony with Zaccarelli et al.'s (2018) statement on the facilitator role of dialogic learning on students' dialogues, arguments and conceptual understanding that are necessary for a disciplinary language.

5.3 Gifted Students' Informal Reasoning Modes After Engaging in Dialogic Discussions Using SSICCs (RQ3)

As seen from Fig. 6, the high school students focused on different informal reasoning modes of SSI before and after the dialogic discussion. This may stem from the nature of SSI, which is open-ended, complex and multi-dimension (e.g., Kolsto, 2001; Sadler, 2004). Further, this may result from the influential role of perceptual selectivity and worldview on individual differences or views (e.g., Atasoy et al., 2022; Cobern, 1996). For example,

even though the students' informal reasoning modes of CL included the highest variation for all teachers before the dialogic discussion (see Fig. 6), the dominant informal modes (e.g., ethical, ecological, technological, social and economic) were varied (Atasoy et al., 2022). Namely, while ethical and ecological modes were common for the students' informal reasoning, they handled different modes. Only two of teacher Ela's students referred to a medical one. This may be seen as the variation of learning. However, they may have paid more attention to some informal reasoning modes than others.

After the dialogic discussions, their informal modes refined or enhanced regarding the type of SSI. This may be recognized as the limited relationships between informal reasoning modes and type of SSI. For example, although SSICCs focused on some informal reasoning modes (see Fig. 2), the students' responses only included some of them. That is, their responses somewhat contained the targeted informal reasoning modes after the dialogic discussion. For example, because SSICCs aimed to handle social, medical and ecological informal reasoning modes for GMO, the high school students referred to both targeted and unplanned modes (e.g., ethics and economic). This may be seen as the potential role of SSICCs at organizing dialogic discussions through educational goals and framing informal reasoning modes (Howe & Abedin, 2013). However, the findings of unplanned modes can be interpreted with the power of SSICCs that enable the students to see other informal reasoning modes that might be implicitly relevant with SSI. Phrased differently, SSICCs and related in-class discussions helped the students notice alternative views and evaluate them through their discussions in terms of various informal reasoning modes (Atasoy et al., 2019; Wu & Tsai, 2011). This may stem from the focus of the dialogic discussion, which offers opportunities for students to actively participate in elaborating ideas, noticing different views, and making their understanding and reasoning clear. This is consistent with Hennessy et al.'s (2023) statement that high levels of elaboration, querying, and students' participation via dialogues or dialogic learning promote a productive learning environment to watch themselves think. For instance, the students added new informal reasoning modes for SC, EA, GN, XR, SP, and GMO and gave up some of their pre-informal reasoning modes for AMT, TT, CL, and HPP after the dialogic discussion (see Fig. 6). This suggests that SSICCs and in-class discussions provided good opportunities for the students to critically re-think about their informal reasoning modes and capture the role of the dialogic discussion and the significance of the negotiation in the nature of science (Lee, 2007; Pedretti, 1999; Sedova et al., 2016). This may result from SSICCs and related dialogic discussions asking the students to look for new evidence and insight about relevant SSI to make more plausible and logical decisions (Cho et al., 2008; Choi & Yoon, 2014). That is, engaging the students in thinking about dialogic discussions and revising their own dialogues or ideas, SSICCs may have influenced their informal reasoning modes (e.g., Atasoy, 2018; Atasoy et al., 2022; Cavagnetto & Hand, 2012; Chin & Teou, 2009). Such a dialogic pedagogy highlights Sedova et al.'s (2016) argument about the constructive role of negotiation on strong discussions involving proper informal reasoning modes. That is, the present study strived to prioritize the dialogic discussion via SSICCs to activate and provoke the key features of dialogic learning/pedagogy (e.g., elaboration, querying, and student participation) (Hennessy et al., 2023). Thus, it seems to have established a productive discussion environment that supports the students' metacognition and improves the quality of student engagement/contribution. This argument advocates Hennessy et al.'s (2023) and Howe et al.'s (2019) statements on the influential role of dialogic learning/pedagogy on students' metacognition and the quality of their engagements. Indeed, this also sheds light on the framework of the current research process with feedback meetings that fostered the teachers to create a more productive discussion environment in their classrooms that pose the students' decision-making

competences and informal reasoning modes. This may have contributed to the variations in informal reasoning modes and better dialogic learning (Zaccarelli et al., 2018).

6 Implications

The students were exposed to a 22-week presentation via SSICCs developed by the authors. Future research may encourage them to prepare their own SSICCs and animate them via Web 2.0 tools (i.e., Toondoo, Pixtoon, Powtoon, and GIF animation). Thereby, they will have more opportunities to engage key features of the dialogic discussion. Also, follow-up or longitudinal studies should be undertaken to make the dialogic discussion sustainable and create dialogic class ethos. Given the SAC teachers' dialogic discussions, teacher professional development programs should be carefully designed and practically implemented to educate in-service teachers about dialogic pedagogy and related strategies via SSICCs. For example, Japanese lesson study may be an alternative way to design, implement, negotiate, revise, and re-implement dialogic lesson plans intertwining SSI, concept cartoons, decision-making competences, and informal reasoning modes. Since the teachers improved their pedagogical competences about the use of SSICCs and in-class dialogic discussions that develop the students' decision-making competences and informal reasoning modes, professional development programs should be developed and implemented to cultivate their pedagogical competences at blending well-known educative tools (e.g., concept cartoons) with the contemporary pedagogical strategies (e.g., dialogic discussion). Such programs may also enable them to learn how to manage, deliver, and develop the dialogic discussions via SSICCs. Thus, SSICCs may not only increase their familiarity with SSI-based science teaching but also afford them to capture how to shift or evolve the monologic discussion to dialogic one.

Because the current study concentrated on gifted students, a comparative study between gifted and regular students should be undertaken to examine the extent to which the dialogic discussion with SSICCs affects their decision-making process, argument quality, and informal reasoning modes. Moreover, the current study did not unveil the teachers' content knowledge, pedagogical content knowledge of SSI, and dialogic learning prior to the dialogic discussion. Thus, these issues can be seen as the limitation of the study. Future research may focus on these missing issues to minimize their uncontrolled effects on SSICCs and decision-making process. Likewise, the study employed a small-sample size due to the number of the students in the SAC. This can be seen as another limitation. Thereby, the intervention focusing on the dialogic discussions should be conducted with a large sample-size to get more insights about its effectiveness in crowded classes or different variables (e.g., educational background, ethos, and locality of SSI). Furthermore, the present study did not examine the teachers' beliefs of science teaching and observe their instructional performances before the implementation of the dialogic discussions. This may be considered as an additional limitation of the study. Future research should investigate these crucial variables to effectively interpret their results of SSICCs and the dialogic discussion. Since the dialogic discussions through SSICCs enabled the students to explain their own arguments and notice peers' informal reasoning modes and decisions, such dialogic discussion-based implementations ought to be used for different science topics.

7 Declarations

7.1 Ethics Approval and Consent to Participate

All students and their parents provided informed consent/assent. The authors stated that the study was approved by the Ethics Committee at BLINDED on BLINDED with approval number BLINDED. Also, the authors stated that all procedures performed in this study followed the ethical standards of the Department of Health Standards on Human Research (DOH/QD/SD/HSR/0.9) and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Author Contribution All authors made an equal contribution to the paper in terms of conceptual framework. Also, the first author was responsible for data collection and writing its draft version. The first four authors contributed to data analysis. The first three authors conceptually improved and professionally edited the draft version. All authors have agreed with the results and conclusions.

Funding Open access funding provided by the Scientific and Technological Research Council of Türkiye (TÜBİTAK). This study was funded by The Scientific and Technological Research Council of Türkiye (Grant Number 117K137).

Data Availability To ensure personal data confidentiality, the datasets are not submitted to a repository. Any question about data sharing may be submitted to the corresponding author.

Declarations

Conflict of Interest The authors declare that they have no conflict of interest.

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