Can. J. Sci. Math. Techn. Educ. (2021) 21:553–570
https://doi.org/10.1007/s42330-021-00166-2

Elementary Students' Epistemic Understandings in Their Classroom Scientific Argumentation

Qingna Jin[1] · Mijung Kim[1]

Accepted: 1 September 2021 / Published online: 29 September 2021

Abstract It has been suggested that students' epistemic understandings influence their practice of argumentation. However, how that influence takes place is not yet fully explained. To contribute to the answer to this question, this study explored elementary students' epistemic understandings in their scientific argumentation. A 4-month qualitative case study with descriptive and interpretive emphases was conducted in a grade 5/6 science classroom in Canada. Nineteen students and their teacher participated in this study. Multiple methods for data collection were employed, including observation, interviews, and collecting students' works. It was found that these students were aware of their epistemic understandings. Qualitative data analysis also revealed that students' epistemic understandings can, yet do not always, influence their performance in argumentation by affecting the ways they think and do while engaged in argumentative dialogues. Moreover, it was found that elementary students were capable of refining their epistemic understandings through social interactions with peers and adapting their epistemic understandings in new contexts. Based on the findings, instructional suggestions are discussed to support the development of students' epistemic understandings and argumentation skills.

Résumé Certains prétendent que les conceptions épistémiques des élèves influencent leur pratique argumentative. Cependant, nous ne connaissons pas encore exactement les modalités de ce processus d'influence. Afin de mieux cerner la réponse à cette question, nous explorons dans cette étude les conceptions épistémiques des élèves du primaire à travers leur argumentation scientifique. Sur une période de quatre mois, nous avons conduit une étude de cas de nature qualitative mettant l'accent sur la description et l'interprétation dans une classe de sciences canadienne constituée d'élèves de cinquième et de sixième année. Dix-neuf élèves et leur enseignant ont participé à l'étude. Plusieurs méthodes de collecte de données furent employées, y compris l'observation, des entrevues et le recueil de travaux faits par les élèves. Il a été démontré que les élèves étaient conscients de leurs conceptions épistémiques. L'analyse qualitative des données a aussi révélé que les conceptions épistémiques des élèves peuvent parfois influencer leur performance en argumentation en modifiant leur façon de penser et d'agir dans des situa-

✉ Qingna Jin
qingna@ualberta.ca

[1] Department of Elementary Education, University of Alberta, Edmonton, Canada

tions de dialogues argumentatifs. De plus, il a été établi que les élèves du primaire étaient capables de raffiner leurs conceptions épistémiques en interagissant socialement avec des pairs et en adaptant leurs conceptions épistémiques aux nouveaux contextes. À partir de ces constatations, nous apportons des suggestions en matière d'enseignement qui soutiennent le développement de conceptions épistémiques et de compétences en argumentation chez les élèves.

Keywords Elementary science · Epistemic understandings · Evidence-based argumentation · Qualitative research

Recent studies suggest that engaging students in evidence-based argumentation is effective to enhance their scientific and critical thinking as core elements of science literacy (Choi & Hand, 2020; Christenson et al., 2017; Grooms et al., 2018; Hand et al., 2016). In many of those studies, researchers tended to focus on the final products of argumentation as students' reasoning abilities; thus, there is a lack of information on the process of students' scientific argumentation in classrooms (Chen et al., 2017; Ryu & Sandoval, 2012). The argumentation process includes not only students' observable performances of argumentation but also their inner thinking processes with epistemic beliefs that inform their performing (Chinn et al., 2020; Hogan & Maglienti, 2001; Iordanou & Constantinou, 2015). Understanding these processes, such as how students coordinate claims and evidence during argumentation, is essential for developing appropriate instructional supports to facilitate students' argumentation (Bravo-Torija & Jiménez-Aleixandre, 2018). Therefore, this study looks into the process of student argumentation to understand students' thinking and meaning making through argumentation.

Background

Scientific Argumentation and Epistemic Norms of Argumentation

Aligning with previous research on scientific argumentation (e.g., Evagorou et al., 2020; Ryu & Sandoval, 2012; Wang, 2020), this study understands argumentation as a social practice, highlighting that it is directed to other people or to contemplate the pros and cons of one's own ideas by putting forward and examining available evidence (van Eemeren et al., 1996). Focusing on the process of argumentation, this study distinguishes argumentation from argument. Specifically, we use *argument* to refer to the artefact resulting from a cognitive and interactional process, which is *argumentation* (Ryu & Sandoval, 2012). When engaged in argumentation, students construct, evaluate and revise their arguments to make sense of the phenomenon under investigation and/or to negotiate for collective meaning making (Kim & Roth, 2014).

A scientific argument consists of claims and evidence. In this structure, a knowledge *claim* includes a proposition, solution or position taken through observation or discussion, and *evidence* consists of data and reasoning (Chen et al., 2016; Hand et al., 2021). Data could be any information, such as measurement, observation, experience, knowledge or information from a book or media. Through reasoning (e.g. looking for patterns), data are interpreted into evidence (Chen et al., 2016; Villanueva & Hand, 2011). With this structure of argument, we focused on the way in which students establish and evaluate evidence to support or reject the legitimacy of the claim, which is valued in the scientific community as the enculturation of scientific practice and communication (Jiménez-Aleixandre & Erduran, 2007; McNeill et al., 2016).

Many scholars support that over an extended period, people who participate in a community identified by joint social activities come to share a set of standards and values that shape the behaviours central to the activity (Driver et al., 2000; Ford & Forman, 2006; Kuhn et al., 2010). Therefore, argumentation in school science as a social practice implicates not only competences or skills but also standards and values shared by the members of the learning community. Those standards and values are usually represented as norms of argumentation, particularly epistemic norms (Driver et al., 2000; Kuhn et al., 2013; Ryu & Sandoval, 2012).

Epistemic norms, in a broad sense, are concerned with the process of generating and validating science knowledge, that is, what can be counted as legitimate in the science community (e.g. the accepted methods to be used, the data appropriate to be collected and interpreted; Ryu & Sandoval, 2012). In the context of students' scientific argumentation, epistemic norms include norms related to evidence, such as what students think counts as evidence and how students decide what sort of evidence supports or refutes a particular claim (Chen et al., 2016; Iordanou & Constantinou, 2014).

Researchers (e.g. Ryu & Sandoval, 2012; Sampson & Clark, 2008) state that whether and how students understand these epistemic norms influences their participation in and performance of argumentation, and vice versa. In this study, we use the term *epistemic understandings* to refer to students' understandings about the epistemic norms of argumentation, that is, students' understandings and knowledge about "*what* and *how* to argue to produce desired knowledge" in their science classroom (Chen et al., 2019, p. 1240, emphasis in original).

Individuals' epistemic understandings are tied to specific content and context (Chen et al., 2019; He et al., 2020). Accordingly, in this study, which explored elementary students' epistemic understandings, we focused on their knowledge and beliefs about and approach towards evidence in their dialogical argumentation. In particular, emphasis was placed on the following aspects, which have been suggested in the literature as central to epistemic understandings and appropriate for young learners (e.g. Chen et al., 2016, 2019; Hogan & Maglienti, 2001; Kuhn et al., 2013; Ryu & Sandoval, 2012; Villanueva & Hand, 2011; Yang et al., 2018):

1. *Importance of evidence*: students' knowledge or understandings about whether and how evidence is important to make a claim
2. *Sufficiency of evidence*: students' knowledge or understandings around the quantity and sufficiency of evidence cited to justify a claim
3. *Validity of evidence*: students' knowledge or understandings around the validity and trustworthiness of evidence, such as knowing how to make sure the data collected are valid and interpreted appropriately and thus can be counted as evidence to support claims
4. *Relevance of evidence*: students' knowledge or understandings about how relevant the evidence is to justify a claim, such as knowing that evidence needs to be relevant and data need to be thought about with respect to the inquiry question in order to be used as evidence

Students' Epistemic Understandings Influence Argumentation Performance

One of the aims of research on argumentation is to get students to argue like scientists by using evidence to support their claims (Sandoval & Millwood, 2008). The coordination of claims and evidence inherently involves students' epistemic understandings. For example, to formulate a quality argument, students need to coordinate their understanding of the phenomenon under investigation with their understanding of what counts as a good and convincing argument (Sampson & Clark, 2009). Consequently, it has been widely suggested and accepted that students' epistemic understandings influence and even determine how they perform argumentation (Duschl, 2008; Hogan & Maglienti, 2001; Kawasaki et al., 2014; Ryu & Sandoval, 2012; Sampson & Clark, 2008).

Kuhn's (2010) model helps explain how individuals' epistemic understandings regulate their argumentation performance. To explain the development of argumentation skills, Kuhn (2010) proposed a theoretical framework in which development of strategies and skills at the procedural level is supported and regulated by development at the metalevel. One's evidence-related epistemic understanding is part of the metalevel understanding of argumentation in this model, and thus regulates procedural components of argumentation, such as processing others' input and constructing one's own responses (Kuhn, 2010). Therefore, as epistemic understandings develop, theoretically, they would support the execution of argumentation skills and strategies at the procedural level (Kuhn, 2010; Kuhn et al., 2016).

This influence of epistemic understandings on argumentation performance may have been considered as a matter of course, since it certainly makes sense that students' ideas about what counts as a good argument, reasonable evidence and so forth ought to affect how they argue. Therefore, limited empirical studies have investigated how this influence takes place. Despite this influence being theoretically suggested and widely accepted, there is limited empirical evidence to explain how it occurs. Questions such as whether and how students' performances of argumentation are determined by and thus consistent with their epistemic understandings are still not clear.

Researchers suggest that it is important for learners to be aware of their own epistemic beliefs and understandings for the purpose of learning, especially transferring learning into new situations (Clyde & Wilkinson, 2019). In terms of argumentation, Iordanou and her colleagues (e.g., Iordanou, 2010; Iordanou & Constantinou, 2014) suggest that being aware of one's epistemic understandings supports the transfer of argumentation strategies and skills. Students in Iordanou (2010), with their awareness of the evidence-related argumentative strategies they used, brought and applied these strategies and skills in new argumentation tasks. In their later research with preservice science teachers, Iordanou and Constantinou (2014) confirmed that enhanced awareness of the use of evidence in argumentation supported the transfer of individuals' skills and strategies of employing evidence in dialogical argumentation. The importance of being aware of one's own epistemic understandings has been recognized; however, limited research on student argumentation has explored students' awareness of the use of evidence, especially younger learners such as elementary children.

Epistemic Understandings Develop Through Participating in Argumentation

While researchers argue that understanding epistemic norms of argumentation is essential for students' scientific argumentation, they have pointed out that students usually lack such understandings (Ryu & Sandoval, 2012; Sampson et al., 2011). Scholars explain that failing to facilitate students' epistemic understandings is the main reason why some instructional supports that aim to improve student argumentation end with unsatisfying outcomes (Sampson & Clark, 2009; Sampson et al., 2011). Thus, investigating how students come to appreciate and understand epistemic norms holds pedagogical significance, since it is important for developing appropriate instructional supports to facilitate students' epistemic knowledge and argumentation skills.

Previous research has provided valuable information on how students develop their knowledge about norms of argumentation (e.g. Ryu & Sandoval, 2012; Schiefer et al., 2020). Through participating in argumentation in a science classroom in Ryu and Sandoval's (2012) study, third- and fourth-graders refined epistemic norms, such as what counted as persuasive evidence and how to persuade with evidence. Through observing and analysing students' performances (e.g. argumentative discourses), Ryu and Sandoval identified the improvement of students' understandings of epistemic norms and thus provided valuable information about supporting students' epistemic understandings through engaging them in argumentation. Sustained practice in argumentation has the potential to improve not only students' argumentation skills but also their evidence-related epistemic understandings. However, in Ryu and Sandoval, how these elementary children thought during the process, whether they were aware of their own epistemic understandings, and whether the thinking behind their performance was consistent with what was observed, etc., were unknown. Given that students' awareness of their argumentation practice is critical for developing and transferring argumentation skills (Clyde & Wilkinson, 2019;

Iordanou, 2010; Iordanou & Constantinou, 2014), there is a need to further explore students' epistemic understandings in the context of classroom scientific argumentation.

Some studies in the literature have provided insights concerning how to support individuals to be aware of their evidence-related epistemic understandings. Preservice science teachers in Iordanou and Constantinou's (2014) study enhanced their metalevel awareness of the use of evidence in argumentation through engaging in reflective activities during argumentation. During their argumentative practice, these student teachers were asked to explicitly reflect in groups on "whether they had used evidence in the arguments and counter-arguments they had produced" and "the quality of the evidence used" (Iordanou & Constantinou, 2014, p. 45). Engaging in these reflective activities, which were designed as the intervention, preservice teachers became aware of their evidence-related epistemic understandings, such as knowing the importance of using evidence to justify and addressing the opposing claim in argumentation. Their awareness was enhanced by sustained practice of those reflective activities.

Without designed research interventions, students are capable of initiating metalevel reflections during their argumentative practice (Kuhn et al., 2013). Working with middle-school students in a philosophy class, Kuhn et al. (2013) identified students' *metatalk*, which refers to talk about argumentation rather than about topics under investigation. Through metatalk with peers, students in Kuhn et al. (2013) developed and refined their understanding of epistemic norms of argumentation (e.g. "key norm pertained to the role of evidence in argument"; p. 473).

Participation in metatalk requires students to be aware of and able to share their own understandings of epistemic norms of argumentation. Students' awareness of their epistemic understandings manifest and are communicated in their metatalk. Kuhn et al. (2013) research on metatalk is important because it shows that it is possible for students to initiate explicit communications on argumentation without designed interventions, and these metalevel communications potentially develop their epistemic understandings. Research on elementary students' metatalk in science classrooms is rare. Thus, whether younger students are capable of initiating and benefitting from their metatalk in science classrooms is less known.

Research Purpose

Given the aforementioned gaps in the literature, the purpose of this study was to explore elementary students' epistemic understandings in the context of classroom scientific argumentation. In particular, this study aimed to answer the following research questions:

1. Are elementary students aware of their evidence-related epistemic understandings while practicing scientific argumentation? If so, how does their awareness affect their argumentation practice?
2. How do students develop their evidence-related epistemic understandings by engaging in argumentation in science classrooms?

Methods

This 4-month-long research was designed as a qualitative case study with descriptive and interpretive emphases (Merriam, 2016). Descriptive case studies in education are useful for presenting basic information about areas of education where little research has been conducted (Merriam, 1998), such as elementary students' awareness of their epistemic understandings in this study. In addition to including rich and thick descriptions, these descriptive data were also used to interpret how students' epistemic understandings affect their argumentative performance, and vice versa.

With this interpretative emphasis, this study set out to "illustrate, support or challenge theoretical assumptions held prior to the data gathering" (Merriam, 1998, p. 38), such as the widely accepted and assumed influence of epistemic understandings on argumentation.

The case study has been challenged in terms of the validity and generalizability of the research findings. In response, we used two approaches suggested in the literature: thick description (Guba & Lincoln, 1989) and triangulation of multiple data sources (Creswell & Miller, 2000). The following sections provide detailed descriptions of the research context and how data from multiple sources were collected and triangulated.

Research Participants and Curriculum Context

This study took place in a grade 5/6 science classroom in a public school in Canada. One teacher, Ms. Bowen, and her 19 students (12 in grade 6 and 7 in grade 5) participated in this study, including 4 girls and 15 boys. During the research period, they studied two units: (1) Sky Science and (2) Air, Aerodynamics, and Flight. According to the teacher's pedagogical preference, both units were delivered as project-based learning with an instructional focus on evidence-based problem solving. Table 1 provides an overview of these two units.

Usually, Ms. Bowen would organize students together at the beginning of each class to introduce the learning activities, give necessary guidance, encourage students to share their thoughts or prior knowledge, lead whole-class discussions about anything that interested or concerned the students, etc. Then, students would be dismissed to work individually or in small groups with the given learning tasks. At the end of each class, students would be gathered together again to share what they had gained or achieved in the class or any questions or thoughts they had.

The unit of Sky Science started with a review of science concepts based on the provincial curriculum, such as phases of the moon and planets and their moons. After that, the teacher introduced a NASA technology design project. In the scenario built by Ms. Bowen, students were expected to act like innovative technologists at NASA and design a technology to advance NASA's current space explorations. Students knew from the beginning of the project that they would make a presentation and that their technologies would have to be approved and supported by the panel from NASA, which consisted of their teacher and classmates. Their designs were to be based on their experiences, knowledge learned in the unit and information from online research on their topics. On the presentation days and after each presentation, there was some time for idea sharing and discussion. During that time, the audience asked questions or gave comments, and the presenters responded to the audience. When different ideas appeared, students would justify themselves with evidence, and argumentative dialogues occurred.

The unit of Air, Aerodynamics and Flight started with learning science concepts such as properties of air and Bernoulli's principle, followed by a parachute design project. Students worked on this activity in small groups. As a group, students needed to make decisions about their designs (e.g. materials, size, shape). With the aim to achieve consensus, students would negotiate through providing and examining each other's evidence when different ideas arose in their groups. In this way, argumentative dialogues took place in the group problem-solving context as well. With their design plans, students were provided materials to build, test, and improve their parachute models to make their models strong and of good quality. They decided to do the final test using quail eggs. That is, a quality parachute (model) should safely land quail eggs from the second floor of their school building.

By designing and implementing these two projects, Ms. Bowen aimed to raise students' awareness of evidence and provide students opportunities to practice evidence-based thinking and problem solving.

Table 1 Overview of the science units in Ms. Bowen's class

Learning unit	**Classroom activities**	**Number of lessons**
Sky Science Unit: NASA technology design project	Learning science concepts based on the curriculum	3
	NASA technology design project introduction: Students knew they would present their own design and evaluate others at the end of the project	1
	Students did their online research and proposed their designs	2
	Students further developed their designs, got feedback from the teacher and peers, and prepared for their presentations	5
	Students presented their NASA technology designs	2
Air, Aerodynamics and Flight Unit: Parachute model design project	Learning science concepts based on the curriculum	4
	Project introduction; Students worked on parachute model initial design in small groups	2
	Students built and tested their parachute models	3
	Students improved their design plans and rebuilt/modified their parachute models	3
	Final parachute model testing	1

Data Collection and Analysis

Multiple methods were employed for data collection. We observed classroom activities, took field notes and collected students' works, such as their NASA technology presentations and parachute design plans. We also video-recorded all the classes throughout the research period, including students' group work and teacher-led whole-class discussions. With the aim to approach students' awareness and thinking processes during argumentation, we adopted two kinds of self-report interviews: in-class informal interview and stimulated recall interview. When students are interviewed to report their thinking processes, memory failures and distortions might occur (Veenman, 2005). As a result, students might know more than they tell, and they sometimes tell more than they know. In-class informal interviews minimize the potential memory failures and distortions by interviewing students concurrently with their task performance.

During the classroom observations, we noticed some "specific incidents or behaviours" that we used as "reference points" for subsequent in-class informal interviews (Merriam, 2016, p. 139). With these interviews, we probed students' inner awareness and thinking processes behind these discerned incidents and behaviours (Veenman, 2005). Stimulated recall interview (SRI) has also proven to be a useful method for circumventing the memory-failure or distortion problem to gather appropriate data on students' awareness and thinking processes (Anderson et al., 2009; Veenman, 2005). During SRIs, students reviewed episodes from the videotapes of their task performances to reproduce their thought processes, followed by reflection on their thinking at that time (Thomas & McRobbie, 2001). In this way, SRI provided us a rich and highly qualitative means to elucidate students' awareness and thinking processes within the context in which they were situated (Anderson et al., 2009). Eight students participated in the first round of SRIs right after they completed their NASA presentations. Seven students participated in the second round at the end of the parachute project.

Classroom videotapes were reviewed immediately after they were collected. After reviewing the classroom recordings, we selected episodes of students' argumentative discourses and/or indicators of students' epistemic understandings. Some of these episodes were shown to students during their SRIs. These selected classroom episodes and student interviews, both the in-class informal interviews and the SRIs, were transcribed for further analysis. Multiple data were then organized into clusters for thematization. Each cluster consisted of relevant data, including classroom recordings, SRIs and in-class informal interviews, students' works and/or researchers' field notes. For example, in the case of the argumentative dialogue between Henry and Nate (see Episode 01 in the next section), by reviewing the classroom recordings, we identified the dialogue between Henry and Nate as an episode of importance. This episode was shown to both Henry and Nate during their subsequent SRI sessions. Therefore, this cluster of data included (1) the classroom recording of the dialogue between Henry and Nate; (2) SRIs with Henry and Nate in which they shared how they thought while they were engaged in that dialogue; (3) Henry's presentation, about which he and Nate exchanged their different ideas and (4) researchers' field notes about the argumentative dialogue between Henry and Nate.

In this way, we collected 53 clusters of data in total. Each cluster was analysed as a whole to interpret student argumentation through reviewing and cross-checking these data. We first analysed the data separately. Then, through critically comparing and examining each other's interpretations, we achieved collective data interpretations. Throughout the data analysis and the following presented research findings, pseudonyms are used to ensure the anonymity of the participants.

Findings

Three key themes relating to students' epistemic understandings were identified in this study.

1. The influence of epistemic understandings on argumentation practice is complex and uncertain, especially in socially interactive contexts (RQ1). In this study, students who participated in interviews showed their awareness of their epistemic understandings. With classroom observations and interviews, it was noticed that, in many cases, students employed their awareness to regulate their argumentative practice, including how they thought and what they did during argumentation. However, in other cases, students did not apply their epistemic understandings in the actual dialogical argumentation, despite being aware of it. Students' epistemic understandings affect their argumentation performance; however, it is not a matter of course that occurs in all situations.
2. Social interaction has the potential to refine one's epistemic understandings (RQ2). When students in this study had the opportunity to share their diverse knowledge about the use of evidence in argumentation, their epistemic understandings were refined and developed through these communications.
3. Epistemic understandings are tied to specific content and contexts, and thus can and need to be adapted in new situations (RQ2). When students moved from the first unit to the second, which were two different problem-solving situations, they adapted their epistemic understandings by examining their task performances and the applicability of their existing knowledge about evidence in the new context.

These themes were commonly found across datasets (i.e. clusters of data in this study), and therefore were presented as the main findings. However, because it is not possible or necessary to present all the supportive data sets, distinctive exemplars were selected to illustrate the findings. These illustrating examples were chosen on the basis of the extent to which they could represent the case of this study (i.e. the science class including Ms. Bowen and her 19 students), or, specifically, "cases within the case" (Stake, 2000, p. 447), that is, students who were closely observed and interviewed in this study. In what follows, these themes are illustrated with one or two selected distinct examples as the supportive evidence.

Theme 1: Epistemic Understandings Influence Argumentation Performances, But Not Always

Students who participated in interviews in this study were aware of their evidence-related epistemic understandings, and their awareness influenced how they performed scientific argumentation. Students were aware of their understandings about evidence, such as knowing the necessity of evidence to justify a claim and the importance of providing sufficient and valid evidence. By applying their epistemic understandings, they regulated their performances during argumentative dialogues with peers. In what follows, we present an excerpt of students' discussion after their NASA technology presentations. During the discussion, students shared different ideas on the presented topics, which developed a dialogical form of argumentation among themselves.

Example 01: Students Applied Their Epistemic Understandings to Regulate Dialogical Argumentation

Henry's design was a space sports centre. After his presentation, Nate asked Henry how he would "send off [his] space centre into space." Henry answered, "I will use gas, just like the gas cars use." In response, Nate made a rebuttal that "gas is not the most efficient fuel; you will need a lot of gas, and it will generate lots of carbon dioxide." He proposed a counter-claim by saying, "I use anti-matter as the power for my rocket," followed by the supporting evidence that "anti-matter is more efficient and cleaner than gas." Then, Henry said he "will consider" Nate's ideas. Henry later added "an anti-matter power" part to his assignment that he submitted to the teacher.

This dialogue was identified as an important moment of dialogical argumentation, and thus was brought to the SRI sessions with Nate and Henry in which they separately shared what and how they were thinking at that time. Nate shared:

> *I was thinking, okay, this is going to happen, then, how? . . . He [Henry] needs evidence for the how. Without it, his [argument] is not convincing. So, I was not convinced as the NASA panel. . . . I was thinking he might forget to put certain information to explain. We need information, lots of, enough information, evidence, to persuade . . . so, I asked that question, asked him to provide his evidence. . . . I did research on fuel. My rocket needs fuel too. . . . I think I know fuel well . . . so I also shared with him my research.*

Nate's epistemic awareness of the importance and sufficiency of evidence manifested when he explicitly expressed "we need... enough... evidence to persuade," even though he was not clear about the difference between information (i.e. data) and evidence, as these two terms were used interchangeably in his interview. With this awareness, he examined Henry's evidence and realized that he was not convinced because of the lack of necessary evidence in Henry's argument. Therefore, Nate raised a question to Henry, asked him for more evidence and shared his own ideas and evidence. As with Nate, through SRI, we learned Henry's thinking process at the time. Henry shared,

> *I know his [Nate's] idea was good, made sense to me. I knew that was from his research. He researched on scientific research NASA has done. That is reliable. . . . Research is always good evidence . . . so, I agreed to take it. And more evidence is always good for my work.*

Henry knew Nate's idea was based on NASA's scientific research, which he believed was a reliable information source for valid evidence. He also knew that citing more evidence would strengthen his argument. Therefore, he decided to accept Nate's idea and included it in his project as another piece of evidence to support his claim. With his own understandings around evidence, Henry evaluated Nate's evidence as reliable and revised his ideas by accepting Nate's.

This example, from both Nate's and Henry's perspectives, illustrates how students' awareness of the use of evidence in argumentation influenced their performance during argumentative dialogue. They consciously applied their evidence-related epistemic understandings to inform how they would think and do as they examined available evidence to raise questions or revise their initial ideas.

Many other similar examples were identified during the data analysis, illustrating that students employed their awareness of the use of evidence to regulate their argumentative practice. Even though the influence of students' epistemic understandings on how they perform argumentation was evident in many classroom situations, it did not occur in all situations as a matter of course. In some situations, it was noticed that students' epistemic understandings failed to affect their argumentation performance, despite them being aware of it. What follows is one of the identified illustrating episodes.

Example 02: Epistemic Understandings Failed to Affect Argumentation Performance

During the teacher-led whole-class discussion in the second unit, Ivan shared how he and his group would solve disagreements within their group through providing and examining each other's evidence:

> *If we have different ideas, we should discuss, take the turn to say our ideas . . . discussion can solve [the disagreement] because reasons and evidence are always important . . . we should, we will compare evidence and make our decision.*

Thus far, Ivan's awareness of the importance of evidence manifested as he explicitly expressed his ideas about how his group would make their decision through comparing and examining available evidence. However, when Ivan was working in his group with Judy and Jeff, sharing or examining evidence for decision-making did not happen in the group interactions. For instance, the following dialogue took place when the group was working on the parachute project and trying to decide how many shroud lines they wanted to have for their parachute model.

2-1 Ivan: We should have 10 [shroud lines].
2-2 Judy: Is that too much? How about four, with one on each corner? So, we can manage the balance, and not too heavy.
2-3 Ivan: No, it should be 10, we need 10.
2-4 Judy: What do you think, Jeff?
2-5 Ivan: We are going to have 10 [writing down 10 in their document].

When his group members had different ideas (turn 2–2), Ivan ignored them without exploring evidence or justification (turns 2–3, 2–5). Noticing this incident, we initiated an in-class informal interview with Ivan. He shared during the interview that he was certain his idea was the best solution, saying "we don't need to discuss, 10 is the best." Ivan's observed behaviour in the group problem solving and what he shared during the interview were consistent and indicated that he did not apply his knowledge about evidence (i.e. that examining evidence is important for decision-making) when he was actually in the context of argumentation. Ivan's problem solving, as an example, shows that the influence of students' epistemic understandings on their performance of argumentation is complex and uncertain in social interactions in classrooms.

Theme 2: Students Refined Their Epistemic Understandings Through Social Interactions

Regarding how students developed their epistemic understandings, we found that social interactions during their argumentation contributed to the refinement of their epistemic understandings. It was noticed that students' knowledge about evidence-related epistemic norms was diverse as they had various ideas about, for example, how data can be interpreted and used as evidence and what sort of evidence can support or refute claims. When students had opportunities to share these various evidence-related ideas, they recognized the differences in their peers' ideas, and some of them examined and changed their initial ideas through sharing with their peers. In this way, students refined their epistemic knowledge through social interactions.

We illustrate this notion with the following example from the discussion in the Sky Science unit. During the discussion, in addition to talking about science topics under investigation (e.g. whether a space ship can travel at the speed of light), metatalk among students also occurred as they discussed what constitutes good evidence, the importance of evidence and how to interpret data into evidence. With metatalk, students demonstrated awareness of their own epistemic understandings and refined their knowledge about and approach towards evidence through communicating with peers. What follows is an example showing how students refined what sort of evidence they thought to be relevant and supportive of claims in their metatalk.

Example 03: Students refined epistemic understandings through metatalk

Levi's technology, Solitude 1, was a rover to explore Triton. Levi organized and interpreted information he had gathered from reliable sources into evidence to justify his claim that "NASA should support my Solitude 1 because it is a good design." The evidence he presented included the need to explore Triton, benefits of the exploration and the specific design of his rover to make the exploration.

After Levi's presentation, Nathan challenged Levi's evidence, particularly the relevance of Levi's evidence, by asking why he had talked more about the need for exploration than about his rover. Levi answered that it was to support his claim. Then, with the teacher's prompt "Would you like to share why you have that concern?", Nathan elaborated on why he thought Levi's evidence was not relevant:

If you spent more time talking about your topic closely, it will make it stronger. . . . You talked a lot about why human beings should be there. These are not really related . . . not helpful. It needs to be related, then, it is persuasive . . . like 99% should be closely and directly about the topic, the rover design. Otherwise, it is not supporting.

In response, Levi said:

It is related. It is important, actually necessary, to have evidence related to the topic. I said, if we did more research, we could know more, that is why human beings should be there, and my rover is to do the research. They are related to the topic. . . . They might be, seem like, a little bit off topic, but they are supporting, because I curved back and reattached that part back to the system, to the topic, so it is relevant and supporting.

In Nathan's view, information that was cited should be "closely and directly about the topic" to become relevant evidence to support a claim. Levi agreed that it was "necessary to have evidence [be] related to the topic"; he thought as long as he could "curve back and reattach... [the information] to the topic" then it became relevant evidence and supported the claim, even if it might be "a little bit off topic." Thus far, both Levi and Nathan were clearly aware of the importance of including evidence in their arguments, particularly relevant evidence. Yet, their understandings of what and how information (i.e. data) can be used as relevant evidence were different.

This episode was shown to both Levi and Nathan in the later SRI sessions. Through communicating ideas with Nathan, Levi realized that it was helpful to explain how the seemingly off-topic information was connected to the topic and thus eligible as evidence to support his claim. In other words, Levi recognized the importance of making *reasoning* explicit in his argument.

I was thinking, we should definitely have information being relevant to support. . . . With his [Nathan's] question, I think . . . it is good, best actually, to have all the evidence closely related, but if you cannot do that, like mine, it is helpful to explain how they are connected. . . . That would help my work be even stronger and better . . . also good for audience to understand . . . and to persuade the panel.

Levi did so accordingly. Before he submitted his assignment to the teacher, he added an explicit explanation of how "the need to explore Triton" and "benefits of the exploration" supported his claim by writing, "My Solitude 1 will make the exploration come true and bring NASA and human beings all these benefits, so NASA should support Solitude 1." By doing this, Levi made the *reasoning* component in his argument more explicit and further justified why the information he cited became supporting evidence.

Through the metatalk on evidence with Nathan, Levi learned what Nathan thought about evidence and refined his own understanding of "relevant evidence." During the metatalk with Levi, Nathan's knowledge about supporting evidence was also refined. Nathan shared:

After he explained, I can see the connection. His explanation was really helpful. . . . You can talk about other things, but only a little. And you want to make sure you have the explanation, like Levi did [in the conversation], but he forgot in his presentation. . . . Some information might be not obviously, closely, directly related to the topic. They could be evidence too, as long as you explain the connection . . .

Nathan shared that, with Levi's explanation, he could see the connection between the cited information and the topic, which he initially thought not related. In other words, as Levi made his *reasoning* explicit, Nathan was able to recognize why the data were related to the claim, and thus accepted these data as relevant evidence. By saying "information [that] might be not obviously, closely, directly related to the topic... could be evidence too, as long as you explain the connection," Nathan acknowledged the role of appropriate reasoning to develop data into evidence.

In this metatalk, Nathan and Levi demonstrated their awareness of their own epistemic understandings. Through metatalk, their epistemic understandings were also exchanged and refined, particularly around the idea that "evidence needs to be related" and how to explain the relevance. Their metatalk involved the difference between *data* and *evidence*, as well as the role of *reasoning*, both of which are fundamental in argumentation (Sampson & Clark, 2009; Sampson et al., 2011). Through social interactions, students attempted to negotiate how data could become relevant supporting evidence through appropriate reasoning.

Theme 3: Students Adapted Their Epistemic Understandings in New Situations

In addition to the social interactions, we found that students also developed their epistemic understandings through adapting them in new situations. In the unit of Air, Aerodynamics and Flight, students worked in groups to design, test and improve their parachute models. This task was a new learning situation and was different from the NASA technology design project in Sky Science. It was found that students adapted the epistemic understandings they had learned and practiced in the previous project (i.e. NASA technology project in the Sky Science unit) in this new group problem-solving task.

Through examining their task performance and the applicability of their existing knowledge about evidence in the current context, students found that some of their previous evidence-related epistemic knowledge did not work and thus adapted it by considering the characteristics of the new situation. In this way, students developed their epistemic understandings. What follows is one of the illustrating examples.

Example 04: Students Adapted Their Epistemic Understandings in a New Situation

Through group discussion, David, Kenny and Zhao completed their parachute model planning document. According to their initial design, they intended to build a parachute with a piece of nylon fabric as the canopy because, as they wrote in their planning document, "NASA is using nylon to make their parachutes. Using the same material as the real ones will make our parachute fly and land well." After they tested their initial design and in the later improving stage, they revised their design by changing canopy materials.

During his SRI, David shared how and why they made these changes, as well as how his group discovered that their previous knowledge about evidence "[did] not work" in the current task and how they adapted that knowledge for the goal of problem solving in the new situation:

> *When we started making our parachute, we researched on the real ones. . . . We were thinking it would be very cool if we use the same design as the real, then our parachute would work very well, it could be more convincing. . . . We got some useful information from the NASA website too. NASA also makes parachutes, with nylon for the canopy. So, we decided we would also use nylon. We thought it would work well, because, you know, NASA is reliable. . . . We thought we found evidence, good evidence to support our design.*

With their existing understanding of evidence-based problem solving (e.g. knowing that they needed valid evidence and that the NASA website was a reliable source of valid evidence), this group of students explored the NASA website to find valid evidence to support their original design. After they learned that NASA's real parachute canopies were made of nylon, they proposed to use the same material to build their model, because they thought using "the same [materials] as the real [parachutes]" would be convincing to justify that their parachute was good. However, when they tested their parachute, they found that the nylon canopy was too heavy to land slowly and protect their quail eggs. David shared, "We did build a nylon one... but it fell down so fast. That was not good. We need it slow, very slow to protect the quail eggs."

By reflecting on their task performance, they realized that reliable information from an authentic data source was not necessarily supportive evidence to justify their solution, and they had to find another way to achieve their goal in their new problem-solving context. David shared:

> *Using the information from NASA and the same materials as the real one sounds cool, but in this project, it cannot prove our parachute is good, cannot make our small one good. . . . If we can prove, if our eggs are good, not broken, and, if our parachute can carry more eggs, then it is a good parachute. . . . These are good evidence to prove ours is good [design] . . . Even NASA is using that, other real parachutes are made of nylon, but it falls very fast, fails to protect the eggs. Following NASA just does not work.*

With their refined ideas on what data would be valid evidence and how to justify their parachute model in this circumstance, David and his group adjusted how they performed this project and managed to make their parachute as light as possible, using a plastic bag instead of nylon to make the canopy.

David and his group realized that evidence, as well as the criteria for supporting evidence, needs to be situated in specific contexts. They understood that trustworthy information from reliable sources such as NASA could be good evidence to justify their problem solving, yet they also came to know that what counts as good evidence and reasonable justification need to be appropriate to their problem context. Their knowledge about data, evidence and evidence-based justification expanded to address the situation and conditions of their current problems.

Discussion

It has been theoretically proposed and widely accepted that individuals' epistemic understandings influence and even determine their argumentation performance (Iordanou & Constantinou, 2014, 2015; Kuhn, 2010; Ryu & Sandoval, 2012). Using descriptive and interpretive methods, this case study presented a detailed account of students' understandings about evidence-related epistemic norms of argumentation in the science classroom context. It was evident in this study that students' epistemic understandings affected how they practiced argumentation. Seen from this perspective, findings of this study to some extent confirmed this aforementioned widely accepted notion.

Nevertheless, we also observed that students' performances were not always consistent with or regulated by their epistemic understandings. We noticed that some students did not apply their epistemic understandings to claim making and justification in social interactions, even if they were clearly aware of it. For example, Ivan (example 02 in the previous section) expressed his understanding of the importance of evidence to make a claim to solve a problem, yet in the actual group problem solving through argumentation, he did not apply that evidence-related knowledge. Ivan's case, as an example, shows that the influence of students' epistemic understandings on their argumentation performance is complex.

Epistemic understandings do not influence argumentation performance as a matter of course in any situation, as has been generally assumed. With the limited data of Ivan's case, we cannot determine whether Ivan was unable to retrieve and practice his epistemic understanding or whether he deliberately decided not to apply it, because we did not have further opportunities to access Ivan's thinking process. Even though we understand how students' epistemic understandings can impact their performance of argumentation, we cannot explain how and why it did not always influence students' work in this study. We can only assume that the complexity of the performance is related to both epistemic and social aspects. Because applying knowledge is a higher cognitive ability than understanding and knowing, the application of students' epistemic understandings of argumentation may require further effort and practice to develop their argumentation abilities.

Scholars have long argued that the social norms of argumentation, as the unwritten rules of the community, significantly influence student argumentation as well (Kelly, 2008; Lemke, 1990; Michaels et al., 2008; Walton, 1989). Therefore, it is conjectured that the group dynamics and students' personal relationships with each other in the groups, as parts of the social context of their argumentation, might contribute to this noticed phenomenon (i.e. that students did not apply their epistemic understandings in argumentation). The epistemic and social aspects intertwine to explain how students' argumentation is practiced. More empirical research on the complexity of students' decision-making and interactions with others during argumentation is needed to help us better understand the relationship between students' epistemic understandings, social relations and argumentation performance.

Analysing what students performed during argumentative discussion and their reflections on their own thinking and actions during interviews, we found that students were aware of the importance of providing and examining evidence in their claim making and communication with others. During the interviews, some students shared further how they employed their awareness of the use of evidence to regulate their thinking and performing during argumentation. For example, Nate in example 01 was aware of the importance of providing sufficient evidence to support a claim; thus, he consciously examined whether Henry's argument had enough evidence. When he realized Henry's evidence was not sufficient to convince him, Nate posed his question to Henry and asked for more evidence. Being aware of their own epistemic understandings not only helped students regulate how they practice argumentation, but also facilitated the development of their epistemic understandings. Elementary students in this study refined their epistemic understandings through social interactions with peers (i.e. metatalk) and adapted their knowledge about evidence and justification in new situations. These findings are encouraging for educators who strive to support students' epistemic understandings and argumentation skills. It is noteworthy that both the refinement and adaptation of epistemic understandings depend on students' awareness of their own epistemic understandings. When students were aware of their own knowledge and beliefs about evidence, such as knowing what counts as evidence, how to interpret data into evidence and what sort of evidence supports or refutes a particular claim, they could express and share those ideas with others, as well as examine whether these ideas (i.e. their existing epistemic understandings) were suitable in a new context. If they lack this awareness, refinement and adaptation are unlikely to occur.

Like the middle-school students in philosophy class in Kuhn et al. (2013), younger learners in the science class in this study were capable of initiating metatalk, which refers to conversation about argumentation and/or the components of an argument rather than science topics under investigation. Through these conversations, students demonstrated, communicated and refined their epistemic understandings. Students' metatalk in this study (e.g. the conversation between Nathan and Levi, see example 03 in the previous section) involved fundamental issues in argumentation, such as the difference between data and evidence, and how data can be interpreted into and counted as evidence through reasoning (Chen et al., 2016; Hand et al., 2021; Sampson & Clark, 2009; Sampson et al., 2011). As a community united by scientific practice (e.g. scientific argumentation), students also negotiated norms of the use of evidence through their metatalk, including the importance of providing evidence and making their reasoning explicit by explaining how the data connected to the claim and thus counted as evidence. These findings support the notions in the literature that argumentation as a form of social practice should be learned by participating in it (Kim & Roth, 2014) and explicit reflections on, and communications about argumentation help the development of student argumentation (Iordanou & Constantinou, 2014; Kuhn et al., 2013; Shi, 2020). Thus, on a pedagogical level, these findings suggest that engaging students in argumentative practice and explicit conversations about argumentation could be a promising approach to improve students' epistemic understandings and argumentation skills.

Limitations of this Study

Findings from this study highlighted the importance of students' awareness of their own epistemic understandings. Among students who participated in interviews in this study, their awareness of their own epistemic understandings was evident. Concerning those students who did not participate in interviews, however, we could not know whether they were aware or unaware of their evidence-related epidemic understandings, or whether and how being unaware would influence their argumentation. We acknowledge this as a limitation of this qualitative case study with a small sample size and suggest more research to explore the question further.

Declarations

Competing Interests The authors declare no competing interests.

References

Anderson, D., Nashon, S. M., & Thomas, G. P. (2009). Evolution of research methods for probing and understanding metacognition. *Research in Science Education*, 39(2), 181–195. https://doi.org/10.1007/s11165-007-9078-1

Bravo-Torija, B., & Jiménez-Aleixandre, M.-P. (2018). Developing an initial learning progress for the use of evidence in decision-making contexts. *International Journal of Science and Mathematics Education,* 16(4)*,* 619–638. https://doi.org/10.1007/s10763-017-9803-9

Chen, Y., Benus, M. J., & Hernandez, J. (2019). Managing uncertainty in scientific argumentation. *Science Education*, 103(5), 1235–1276. https://doi.org/10.1002/sce.21527

Chen, Y.-C., Benus, M. J., & Yarker, M. B. (2016). Using models to support argumentation in the science classrooms. *The American Biology Teacher*, 78(7), 549–559. https://doi.org/10.1525/abt.2016.78.7.549

Chen, Y.-C., Hand, B., & Norton-Meier, L. (2017). Teacher roles of questioning in early elementary science classrooms: A framework promoting student cognitive complexities in argumentation. *Research in Science Education*, 47(2), 373–405. https://doi.org/10.1007/s11165-015-9506-6

Chinn, C. A., Barzilai, S., & Duncan, R. G. (2020). Disagreeing about how to know: The instructional value of explorations into knowing. *Educational Psychologist*, 55(3), 167–180. https://doi.org/10.1080/00461520.2020.1786387

Choi, A., & Hand, B. (2020). Students' construct and critique of claims and evidence through online asynchronous discussion combined with in-class discussion. *International Journal of Science and Mathematics Education,* 18(6)*,* 1023–1040. https://doi.org/10.1007/s10763-019-10005-4

Christenson, N., Gericke, N., & Rundgren, S. C. (2017). Science and language teachers' assessment of upper secondary students' socioscientific argumentation. *International Journal of Science and Mathematics Education,* 15(8), 1403–1422. https://doi.org/10.1007/s10763-016-9746-6

Clyde, J. V., & Wilkinson, G. R. (2019). Rhetorical replay and the challenge of gamic history. In K. Becnel (Ed.), *Emerging technologies in virtual learning environments* (pp. 170–186). IGI Global

Creswell, J. W., & Miller, D. L. (2000). Determining validity in qualitative inquiry. *Theory into Practice,* 39(3), 124–130. https://doi.org/10.1207/s15430421tip3903_2

Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education*, 84(3), 287–312. https://doi.org/10.1002/(SICI)1098-237X(200005)84:3<287::AID-SCE1>3.0.CO;2-A

Duschl, R. (2008). Science education in three-part harmony: Balancing conceptual, epistemic, and social learning goals. *Review of Research in Education*, 32(1), 268–291. https://doi.org/10.3102/0091732X07309371

Evagorou, M., Nicolaou, C., & Lymbouridou, C. (2020). Modelling and argumentation with elementary school students. *Canadian Journal of Science, Mathematics, and Technology Education*, 20(1), 58–73. https://doi.org/10.1007/s42330-020-00076-9

Ford, M. J., & Forman, E. A. (2006). Redefining disciplinary learning in classroom contexts. *Review of Research in Education,* 30, 1–32. http://www.jstor.org/stable/4129768
Grooms, J., Sampson, V., & Enderle, P. (2018). How concept familiarity and experience with scientific argumentation are related to the way groups participate in an episode of argumentation. *Journal of Research in Science Teaching*, 55(9), 1264–1286. https://doi.org/10.1002/tea.21451
Guba, E. G., & Lincoln, Y. S. (1989). *Fourth generation evaluation.* SAGE
Hand, B., Chen, Y.-C., & Suh, J. K. (2021). Does a knowledge generation approach to learning benefit students?: A systematic review of research on the science writing heuristic approach. *Educational Psychology Review*, 33(2), 535–577. https://doi.org/10.1007/s10648-020-09550-0
Hand, B., Norton-Meier, L. A., Gunel, M., & Akkus, R. (2016). Aligning teaching to learning: A three-year study examining the embedding of language and argumentation into elementary science classrooms. *International Journal of Science and Mathematics Education,* 14(5)*,* 847–863. https://doi.org/10.1007/s10763-015-9622-9
He, X., Deng, Y., Yu, S., & Wang, H. (2020). The influence of context on the large-scale assessment of high school students' epistemic cognition of scientific argumentation. *Science & Education*, 29(1), 7–41. https://doi.org/10.1007/s11191-019-00088-4
Hogan, K., & Maglienti, M. (2001). Comparing the epistemological underpinnings of students' and scientists' reasoning about conclusions. *Journal of Research in Science Teaching*, 38(6), 663–687. https://doi.org/10.1002/tea.1025
Iordanou, K. (2010). Developing argument skills across scientific and social domains. *Journal of Cognition and Development,* 11(3), 293–327. https://doi.org/10.1080/15248372.2010.485335
Iordanou, K., & Constantinou, C. P. (2014). Developing pre-service teachers' evidence-based argumentation skills on socio-scientific issues. *Learning and Instruction*, 34, 42–57. https://doi.org/10.1016/j.learninstruc.2014.07.004
Iordanou, K., & Constantinou, C. P. (2015). Supporting use of evidence in argumentation through practice in argumentation and reflection in the context of SOCRATES learning environment. *Science Education*, 99(2), 282–311. https://doi.org/10.1002/sce.21152
Jiménez-Aleixandre, M. P., & Erduran, S. (2007). Argumentation in science education: An overview. In S. Erduran & M. P. Jiménez-Aleixandre (Ed.), *Argumentation in science education: Perspectives from classroom-based research* (pp. 3–27). Springer.
Kawasaki, J., DeLiema, D., & Sandoval, W. (2014). The influence of non-epistemic features of settings on epistemic cognition. *Canadian Journal of Science, Mathematics, and Technology Education,* 14(2), 207–221. https://doi.org/10.1080/14926156.2014.903319
Kelly, G. J. (2008). Inquiry, activity, and epistemic practice. In R. A. Duschl & R. Grandy (Eds.), *Teaching scientific inquiry: Recommendations for research and implementation* (pp. 99–117). Sense.
Kim, M., & Roth, W-M. (2014). Argumentation as/in/for dialogical relation: A case study from elementary school science. Pedagogies, 9(4), 300–321. https://doi.org/10.1080/1554480X.2014.955498
Kuhn, D. (2010). Teaching and learning science as argument. *Science Education*, 94(5), 810–824. https://doi.org/10.1002/sce.20395
Kuhn, D., Hemberger, L., & Khait, V. (2016). Argue with me: Argument as a path to developing students' thinking and writing (2nd ed.). Routledge
Kuhn, D., Wang, Y., & Li, H. (2010). Why argue? Developing understanding of the purposes and value of argumentive discourse. *Discourse Processes,* 48(1), 26–49. https://doi.org/10.1080/01638531003653344
Kuhn, D., Zillmer, N., Crowell, A., & Zavala, J. (2013). Developing norms of argumentation: Metacognitive, epistemological, and social dimensions of developing argumentive competence. *Cognition and Instruction*, 31(4), 456–496. https://doi.org/10.1080/07370008.2013.830618
Lemke, J. L. (1990). *Talking science: Language, learning, and values*. Ablex
McNeill, K. L., González-Howard, M., Katsh-Singer, R., & Loper, S. (2016). Pedagogical content knowledge of argumentation: Using classroom contexts to assess high-quality PCK rather than pseudoargumentation. *Journal of Research in Science Teaching*, 53(2), 261–290. https://doi.org/10.1002/tea.21252
Merriam, S. B. (1998). Case study as qualitative research. In S. B. Merriam (Ed.), *Qualitative research and case study application in education* (pp. 26–43). Jossey-Bass
Merriam, S. B. (2016). *Qualitative research: A guide to design and implementation.* Jossey-Bass
Michaels, S., O'Connor, C., & Resnick, L. B. (2008). Deliberative discourse idealized and realized: Accountable talk in the classroom and in civic life. *Studies in Philosophy and Education*, 27(4), 283–297. https://doi.org/10.1007/s11217-007-9071-1
Ryu, S., & Sandoval, W. A. (2012). Improvements to elementary children's epistemic understanding from sustained argumentation. *Science Education*, 96(3), 488–526. https://doi.org/10.1002/sce.21006
Sampson, V., & Clark, D. B. (2008). Assessment of the ways students generate arguments in science education: Current perspectives and recommendations for future directions. *Science Education*, 92(3), 447–472. https://doi.org/10.1002/sce.20276
Sampson, V., & Clark, D. (2009). The impact of collaboration on the outcomes of scientific argumentation. *Science Education*, 93(3), 448–484. https://doi.org/10.1002/sce.20306

Sampson, V., Grooms, J., & Walker, J. P. (2011). Argument-driven inquiry as a way to help students learn how to participate in scientific argumentation and craft written arguments: An exploratory study. *Science Education*, 95(2), 217–257. https://doi.org/10.1002/sce.20421

Sandoval, W. A., & Millwood, K. A. (2008). What can argumentation tell us about epistemology? In S. Erduran & M. P. Jiménez-Aleixandre (Eds.), *Argumentation in science education: Perspectives from classroom-based research* (pp. 68–85). Springer

Schiefer, J., Golle, J., Tibus, M., Herbein, E., Gindele, V., Trautwein, U., & Oschatz, K. (2020). Effects of an extracurricular science intervention on elementary school children's epistemic beliefs: A randomized controlled trial. *British Journal of Educational Psychology*, 90(2), 382–402. https://doi.org/10.1111/bjep.12301

Shi, Y. (2020). Talk about evidence during argumentation. *Discourse Processes*, 57(9), 770–792. https://doi.org/10.1080/0163853X.2020.1777498

Stake, R. E. (2000). Case studies. In N. K. Denzin & Y. S. Lincoln (Eds.), *Handbook of qualitative research* (2nd ed.; pp. 435–454). SAGE

Thomas, G. P., & McRobbie, C. J. (2001). Using a metaphor for learning to improve students' metacognition in the chemistry classroom. *Journal of Research in Science Teaching,* 38(2), 222–259. https://doi.org/10.1002/1098-2736(200102)38:2<222::AID-TEA1004>3.0.CO;2-S

van Eemeren, F. H., Grootendorst, R., Henkemans, F. S., Blair, J. A., Johnson, R. H., Krabbe, E. C. W., et al. (1996). *Fundamentals of argumentation theory: A handbook of historical backgrounds and contemporary developments.* Lawrence Erlbaum

Veenman, M. V. J. (2005). The assessment of metacognitive skills: What can be learned from multi-method designs? In C. Artelt & B. Moschner (Eds.), *Lernstrategien und metakognition: Implikationen für forschung und praxis* (pp. 75–97). Waxmann

Villanueva, M. G., & Hand, B. (2011). Data versus evidence: Investigating the difference. *Science Scope,* 35(1), 42–45. http://www.jstor.org/stable/43183102

Walton, D. N. (1989). Dialogue theory for critical thinking. *Argumentation*, 3(2), 169–184. https://doi.org/10.1007/BF00128147

Wang, J. (2020). Scrutinising the positions of students and teacher engaged in argumentation in a high school physics classroom. *International Journal of Science Education,* 42(1), 25–49. https://doi.org/10.1080/09500693.2019.1700315

Yang, F. Y., Liu, S. Y., Hsu, C. Y., Chiou, G. L., Wu, H. K., Wu, Y. T., Chen, S., Liang, J. C., Tsai, M. J., Lee, S. W. Y., Lee, M. H., Lin, C. L., Chu, R. J., & Tsai, C. C. (2018). High-school students' epistemic knowledge of science and its relation to learner factors in science learning. *Research in Science Education*, 48(2), 325–344. https://doi.org/10.1007/s11165-016-9570-6

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.