Exploring Students' Metacognition in the Context of Argumentation (Mc-A) in an Elementary Science Classroom

by

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Abstract

The importance of students' metacognition for their argumentation in science classrooms has been theoretically proposed and widely accepted in the literature. Yet, limited research, especially empirical research, has explored students' metacognition in the context of classroom scientific argumentation. This research seeks to fill this gap by exploring students' metacognition in the context of argumentation (Mc-A). This four-month qualitative case study was conducted in a grade 5/6 science classroom in Canada. Eighteen students and one science teacher participated in this study. To engage students in argumentative practices and stimulate their metacognitive experiences, argument-focused metacognitive scaffolds were integrated into the classroom instruction throughout the research period. Two main kinds of scaffolds were implemented by the teacher: questioning and prompting students' thinking during argumentation, and teacher modelling of thinking related to argumentation. With the aim to explore students' Mc-A, this study investigated (1) how students' Mc-A was involved in their argumentative practices in the science classroom, and (2) how the manifestation of students' Mc-A was related to classroom interactions. Multiple methods for data collection were employed, including observation, interviews, and collecting students' writings. Qualitative data analysis revealed that students' Mc-A was involved in their argument construction, argument evaluation, and argumentative dialogue and affected their decision making regarding what and how they would think and do during the processes. It was also found that the manifestation of students' Mc-A was related to their interactions with the teacher, their peers, and the researcher. These findings add to the field's understanding of elementary students' scientific argumentation and the relation between metacognition and argumentation, and suggest pedagogical ways to prompt students' scientific argumentation and metacognition.

Preface

This thesis is an original work by Qingna Jin. The research project of which this thesis is a part received research ethics approval from the University of Alberta Research Ethics Board, Project Name "Students' scientific argumentation," No. Pro00074904, August 21, 2017.

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CHAPTER 1

INTRODUCTION

1.1 Coming to the Research

I am not good at playing the game Go, nor am I a big fan of it. However, as one who grew up in East Asia, where there is a long tradition of playing the game Go, and having also had a chance to take a few Go lessons in childhood, I am familiar with it. At least, I know how complicated it is. Therefore, in May 2018, when I heard the news that a computer system that Google engineers had trained to play the game Go (AlphaGo) had beat the world's best human player, I was totally shocked to learn how intelligent the latest artificial intelligence (AI) is. I cannot stop thinking that we, as human beings, should prepare ourselves for the future society in which we might need to live or work with various AIs.

This news also made me more concerned with a question I have pondered for a long time: What are the important things students should learn in school, especially nowadays in the ever-changing society? I clearly know that this question denies any "right" answer. However, it was through concerning myself with this question that I came to the topic of this study.

In this era of rapid scientific and technological progress and information expansion, it is not possible for individuals to acquire all existing knowledge or to predict what knowledge will be essential in the future. Thus, I agree with the view that preparing students to be independent learners with the ability to learn any knowledge they desire and make informed decisions should be one of the significant goals of education (Kipnis & Hofstein, 2008). When I try to connect this abstract ideal with the particulars of what students should spend their time doing in school, or rather in science classrooms, it is clear to me after constant thinking and reflection on my own learning and teaching experiences that argumentation and metacognition are the most important things that students should learn. I acknowledge and respect that others may have different ideas from mine. This is my very personal journey of how I came to this research topic. I will justify this work in the last section of this chapter. Argumentative practice is essential for the development of children's critical thinking, which is the core of the ability to make informed decisions in the complexity of lifeworld problems in a post-truth society, and metacognitive experiences have the potential to help students learn to use their minds well and learn efficiently. Therefore, argumentation and metacognition became the issues I am eager to pursue as a researcher in the field of education.

1.2 Background Context of This Study

1.2.1 Argumentation as a Core Practice for Scientific Literacy

Scientific literacy is seen as the desirable general outcome of learning science (American Association for the Advancement of Science, 1993; Boufaoude, 2002; DeBoer, 2000; Dillon, 2009; Holbrook & Rannikmae, 2009; Laugksch, 1999; McEneaney, 2003; Osborne & Rafanelli, 2018; Sadler & Zeidler, 2009; Sandoval, Sodian, Koerber, & Wong, 2014). The use of scientific inquiry as an approach to improve students' scientific literacy has been supported by education theorists (Kuhn, 2005), since it has the potential to involve students in authentic investigation of real phenomena and, in the process, foster intellectual skills like those practiced by professional scientists in generating new knowledge (Abd-El-Khalick et al., 2004; Akkus, Gunel, & Hand, 2007; Chinn & Malhotra, 2002; Jiménez-Aleixandre & Erduran, 2007; Kuhn, Black, Keselman, & Kaplan, 2000; Ruiz-Primo, Li, Tsai, & Schneider, 2010; Sandoval, 2005).

To better fulfil its potential as an approach to promote scientific literacy, it is important to emphasize that scientific inquiry goes beyond executing experimental procedures, using instruments, recording data, and reproducing graphs to verify scientific knowledge in textbooks.

It also involves processes of argumentation that scientists undertake when they construct new knowledge, such as constructing knowledge claims through interpreting data to become evidence and then presenting them to a community of peers for critique, debate, and revision (Abd-El-Khalick et al., 2004; Duschl & Osborne, 2002; Sampson & Clark, 2009; Sandoval & Reiser, 2004; Zembal-Saul, 2009). As Duschl and Osborne (2002) assert, “teaching science as a process of inquiry without the opportunity to engage in argumentation . . . is to fail to represent a core component of the nature of science or to establish a site for developing student understanding” (p. 41). Therefore, while learning science through scientific inquiry, students should engage in argumentative practices.

When inquiry-based approaches that emphasize aspects of scientific argumentation are incorporated into students’ learning, students seek evidence and reach collaborative decisions instead of focusing on procedural issues (e.g., performing experiments step by step following the instructions listed in a textbook to confirm that what stated in the textbook is correct). Inquiry-based approaches with the emphasis on argumentation have been identified as possible mechanisms for conceptual growth and change (e.g., Driver, Asoko, Leach, Scott, & Mortimer, 1994; Keogh & Naylor, 1999; Michaels, O’Connor, & Resnick, 2008; Naylor, Keogh, & Downing, 2007), developing complex reasoning and enhancing scientific and critical thinking capabilities (e.g., Bricker & Bell, 2008; Chen, Hand, & Park, 2016; Duschl & Osborne, 2002; Iordanou & Constantinou, 2015; Jimenez-Aleixandre & Erduran, 2007; Kuhn, 1993, 2010; Nussbaum, Sinatra, & Poliquin, 2008; Osborne, Erduran, & Simon, 2004; Walton, 1989), and improving epistemic understanding (e.g., Grooms, Sampson, & Enderle, 2018; Nussbaum et al., 2008; Kuhn, Zillmer, Crowell, & Zavala, 2013; Ryu & Sandoval, 2012). Therefore, argumentation, which is supposed to be emphasized throughout quality scientific inquiry in schools (e.g., as students generate and explore questions, interpret data, and construct statements based on evidence), has been of increasing interest in science education and is seen as a core practice of engaging students in science, thereby promoting their learning and developing their scientific literacy (Braaten & Windschitl, 2011; Cavagnetto, 2010; Duschl & Osborne, 2002; Kim & Roth, 2014; Nielsen, 2013). Consequently, argumentation is also emphasized in many science education curricula. For example, the Next Generation Science Standards (NGSS Lead States, 2013), National Research Council (2012), and American Association for the Advancement of Science (2000) refer to evidence-based argumentation as one of the fundamental practices of science and engineering. The redesigned science curricula in Canadian provinces, such as Alberta (Alberta Education, 2018), British Columbia (British Columbia Ministry of Education, 2016) and Ontario (Ontario Ministry of Education, 2007), have also identified argumentation as fundamental for science education.

1.2.2 Different Theoretical Perspectives on Argumentation

Research on argumentation in science education has exploded over the past decade (Duschl, 2008; Kim & Roth, 2014; Ryu & Sandoval, 2012). It has been pointed out that researchers in this area often fail to articulate the theoretical perspective from which they approach argumentation (Erduran, 2008). When such a perspective is articulated, argumentation is often framed as a specific cognitive skill, or set of skills (Ryu & Sandoval, 2012). Informed by this perspective, various approaches have been developed to help students learn how to participate in scientific argumentation (e.g., Berland & Reiser, 2009; von Aufschnaiter, Erduran, Osborne, & Simon, 2008). These approaches have been reported in the literature with mixed results (Erduran, Simon, & Osborne, 2004; Iordanou & Constantinou, 2015). For example, Zohar and Nemet (2002) reported that "teaching of argumentation skills" increased "the quality of students' argumentation" (p. 35); McNeill, Lizotte, Krajcik, and Marx (2006) reported that instructional support focusing on students' skills of constructing written arguments led to "significant learning gains" (p. 153); and Iordanou and Constantinou (2015) reported that an intervention aimed at developing students' argumentation skills, particularly the skill of using evidence, "help[ed] students learn" and develop "skilled argumentation" (p. 285). In spite of these "successes," some scholars (e.g., McDonald & McRobbie, 2010) suggest that researchers need to be cautious in adopting this perspective (i.e., seeing argumentation as a skill or set of skills), as it tends to lead to the ideas that learning argumentation skills is a prerequisite to being able to engage in argumentation and that those skills can be taught separately from engaging in argumentation.

Deriving from this perspective (i.e., seeing argumentation as a skill or a set of skills), many other instructional approaches place primacy on teaching the structure of the argumentative genre and the skills of constructing and evaluating arguments prior to having students participate in argumentation. According to Kim and Roth (2014), studies with those approaches often fail to bring positive results in classroom environments, especially when students learn through working collaboratively. For instance, in classroom science learning contexts in which those instructional approaches are adopted and children participate in collaborative problem-solving tasks, the processes of constructing and justifying claims are often messy and do not follow the predetermined order (Kim & Roth, 2014). Given the limitations of this theoretical perspective on scientific argumentation (i.e., seeing argumentation as a skill or a set of skills), scholars rooted in the sociocultural perspective (e.g., Kim & Roth, 2014; Ryu & Sandoval, 2012) have proposed alternative ways to theoretically understand argumentation (e.g., argumentation as/in/for dialogical relations [Kim & Roth, 2014] and argumentation as a social practice [Ryu & Sandoval, 2012]). These scholars have argued that argumentation is and should be learned by participating in it. Moreover, according to Ryu (2011), the view of argumentation as a collective social practice "stands in contrast to" the view of argumentation as cognitive skills (p. 135).

Given that different theoretical perspectives on scientific argumentation coexist in the literature, it is important for researchers in this field (i.e., scientific argumentation) to ponder whether the perspectives are mutually exclusive and whether they stand "in contrast to" each other, as Ryu (2011) argued, or are compatible. Thus, more research is needed that provides empirical evidence to enrich the perspectives of theoretically understanding argumentation. This study has aimed to attend to this need. Instead of choosing one of these two theoretical perspectives (i.e., either seeing argumentation as a set of cognitive skills or a form of social practice), this study approaches and explores student argumentation as both a form of social practice and a cognitively demanding task in which individuals' cognitive skills are involved.

1.2.3 Importance of Metacognition for Argumentation

As discussed above, many recent studies in science classrooms have supported the contention that engaging students in evidence-based argumentation, which has been upheld as the core practice for scientific literacy, has the potential to enhance students' reasoning and scientific and critical thinking and promote their science literacy. However, many of those studies focus on the final products and outcomes of argumentation. Researchers tend to compare students' initial and final products to examine changes in the quality of the arguments over different time periods (e.g., Hong, Lin, Wang, Chen, & Yang, 2013; Kelly & Chen, 1999; Ruiz-Primo et al., 2010; Wilson, Taylor, Kowalski, & Carlson, 2010) instead of closely exploring how those changes take place in various contexts. It is important to know the conditions and processes of, for example, how students coordinate claims and evidence during argumentative processes, instead of merely examining the final products of knowledge. Yet, limited studies have explored the process of students' argumentative practice over time (Chen, Hand & Park, 2016), leaving a lack of essential information on the process of students' scientific argumentation in classrooms. Understanding the process of argumentation is essential for knowing more about and then better supporting students' argumentation. The processes, which are not fully clear, include not only students' performing (i.e., observable performances on the cognitive level in argumentative practices), but also their inner thinking processes that inform or affect their performing.

The field of metacognition provides a framework for understanding the inner thinking processes that students engage in during argumentation. Metacognition (n.d.), which Merriam-Webster defines as the "awareness and analysis of one's own learning or thinking processes," is commonly understood as higher-order cognition about cognition (e.g., Flavell, 1979; Veenman, 2012). It has been "awarded a high status as a feature of learning" (Georghiades, 2004, p. 366) because various studies have supported its importance for learning (Conner, 2007). In the field of science education, the importance of metacognition has been increasingly recognized (Thomas, 2012). For example, many studies have reported the positive influence of metacognition on conceptual change in science learning and understanding the nature of science (e.g., Anderson & Nashon, 2007; Conner, 2007; Malone, 2008).

Similarly, scholars have also proposed the importance of metacognition for scientific argumentation (e.g., Duschl, 2008; Garcia-Mila & Anderson, 2007; Jiménez-Aleixandre, 2007; Zeidler & Sadler, 2008; Zohar, 2007). Work in this area has identified the *metalevel understanding of argumentation*, which is also termed *knowledge of argumentation at the metalevel*, as important to students' development of argumentation abilities (e.g., Iordanou &

Constantinou, 2015; Kuhn, 2005, 2010; Kuhn, Hemberger, & Khait, 2016; Kuhn et al., 2013). According to Kuhn (2010), during the process of argumentation, students' metalevel understanding of argumentation regulates and governs the procedural components, such as "processing of . . . others' input and construction of one's own responses" (p. 813). Therefore, she argues, "as metalevel understanding of argumentation develops . . . it supports the execution of argument skills at the procedural [cognitive] level" (p. 821). Kuhn and her colleagues' later work (Kuhn et al., 2013) has provided some evidence to support this viewpoint, thus, to some extent, has affirmed the importance of metacognition for argumentation. With the aim to examine how extended engagement in argumentative discourse with peers influences students' argumentation, Kuhn et al. (2013) report that "adolescents' . . . enhanced understanding of counterargument and use of evidence" (p. 456) affords them an increased ability to address and (attempt to) weaken their discourse opponent's claims, as well as the ability to use available evidence to support their own claims. With this finding, Kuhn and her colleague (2013) affirm the importance of metacognition to students' scientific argumentation.

However, few studies, if any, have specifically explored students' metacognition in the context of argumentation (Mc-A). Therefore, empirical research is needed to explore and provide related information on Mc-A, such as how we can "see" Mc-A, what Mc-A looks like, and whether and how metacognition positively influences student argumentation. Given this gap in the research literature, this study aimed to contribute some insights through specifically exploring students' Mc-A. Exploring students' Mc-A is important because it gathers information not only on how students *perform,* but also on how they *think* during argumentation, as well as how the *thinking* and *performing* interplay with each other. Knowing about these processes is essential, not only for better theoretical understanding of argumentation, but also for developing appropriate instructional support in practice to further facilitate students' argumentation.

1.2.4 Limited Studies of Argumentation at the Elementary Level

According to Metz (2011), opportunities for elementary students to engage in scientific argumentation are "impoverished" (p. 51), because younger students are assumed to have limited reasoning ability, communication skills, and content knowledge necessary for argumentation (Lee & Kinzie, 2012). Therefore, the majority of the research on argumentation in the field of science education to date has focused on the secondary and higher levels (e.g., Chin & Osborne, 2008; Jimenez-Aleixandre, Rodriguez, & Duschl, 2000; Kelly & Takao, 2002; Kerlin, McDonald, & Kelly, 2010; McNeill, 2009; Sampson & Clark, 2009; Scott, Mortimer, & Aguiar, 2006; Walker & Sampson, 2013), while relatively fewer studies have explored students' argumentation at the elementary level.

Studies show that elementary students usually have difficulties in interpreting data to generate evidence, coordinating evidence and claims, and debating their claims in public (Cavagnetto, Hand, & Norton-Meier, 2009; Martin & Hand, 2009). Nevertheless, recent research, even if limited, has demonstrated that learners at the elementary level are capable of engaging in core scientific practices such as scientific argumentation with appropriate support and sufficient time to develop those practices, and their abilities to, for example, construct and evaluate arguments increase as their engagement in argumentation extends (e.g., Choi, Hand, & Norton-Meier, 2014; Lehrer, Schauble, & Lucas, 2008; McNeill, 2011; Reznitskaya, Anderson, & Kuo, 2007; Sandoval et al., 2014; Zangori, Forbes, & Biggers, 2013). However, it is noteworthy that the majority of these studies draw their conclusions through analyzing the products of students' scientific argumentation (i.e., comparing students' initial and final written or spoken texts) either quantitatively (e.g., Choi et al, 2014; Reznitskaya et al., 2007; Zangori et al., 2013) or qualitatively (e.g., McNeill, 2011; Ryu & Sandoval, 2012). Some researchers examined the process of how young children perform argumentation, yet only focused on the cognitive level (e.g., Kim, 2016; Ryu & Sandoval, 2012). In other words, little research has taken children's thinking processes into consideration while trying to investigate younger students' scientific argumentation. Therefore, this study focused on the process of elementary students' argumentation (both *performing* and *thinking*) with the aim of contributing to reducing this gap in the research literature.

Given these gaps in research literature (i.e., the lack of information on the process of argumentation; the lack of empirical evidence for the importance of metacognition to argumentation; the lack of information on how elementary students engage in argumentation), this work focused on the process of argumentation embedded in the social context of the elementary classroom. Particularly, this study investigated elementary students' Mc-A, in terms of exploring how students' Mc-A manifested and how it was involved in argumentation.

1.3 Purpose of the Study and Research Questions

The main purpose of this study was to explore the role of metacognition on students' engagement in argumentative practices in elementary classrooms. In order to explore students' metacognition in the context of classroom argumentation, a case study was conducted in a grade 5/6 science classroom. Over a four-month period, argument-focused metacognitive scaffolds were integrated into the three instructional units focused on developing students' argumentation. Related research has shown that elementary students usually do not spontaneously participate in argumentative practice (e.g., Anthony & Kim, 2014) or reflect on their own thinking or learning (i.e., be involved in metacognitive experiences) (Thomas, 2012). Therefore, in order to engage students in argumentation and stimulate their metacognitive experiences, two kinds of argument-focused metacognitive scaffolds (i.e., *questioning & prompting* and *modelling thinking*) were integrated into the three learning units during the research period. Additional information about the argument-focused metacognitive scaffolds is provided in detail in subsequent chapters.

With the aim to explore elementary students' Mc-A in the context of argument-focused metacognitive scaffolding, I had the following objectives for this study. The first was to describe the nature of students' Mc-A during science-based argumentation tasks, including argument construction, argument evaluation, and argumentative dialogue. The second was to explore possible factors or contextual elements affecting or related to students' Mc-A. Two overarching research questions guided this study:

(1) How is students' Mc-A involved in their argument construction, argument evaluation, and argumentative dialogue in science classrooms?

(2) How is the manifestation of students' Mc-A related to classroom interactions with the teacher, other students, and the researcher?

CHAPTER 2

LITERATURE REVIEW

In this chapter, I describe the literature that has been drawn upon for this work and clarify key terms in this study. The first section focuses on argumentation, specifically argumentation in science classrooms. With the aim of clarifying what *argument* and *argumentation* mean in this study, I explain argumentation as both a cognitive activity and a form of social practice, followed by a discussion of the goals and norms of argumentation. The second section presents research on metacognition and proposes a framework for examining metacognition in the context of argumentation (Mc-A). In the last section, I discuss the important role that pedagogical scaffolds play in creating a classroom context that supports students' engagement in argumentation and development of related metacognitive abilities.

2.1 Argumentation in Science Education

2.1.1 Argument and Its Structure

What is an argument? Toulmin (1958) defines an argument as an assertion and its accompanying justification. Means and Voss (1996) quote Angell's (1964) definition that "an argument is a conclusion supported by at least one reason" (p. 141). Halpern (1989) describes an argument as "consisting of one or more statements that are used to provide support for a conclusion" (p. 177). According to these definitions, an argument consists of either assertions or conclusions (they can also be called claims) and their justifications, reasons, or supports (Zohar & Nemet, 2002). In this study, aligning with those definitions, I use the term *argument* to refer to the artifact resulting from a cognitive and interactional process that I call *argumentation*. Thus, in a classroom setting, an argument can be any spoken or written text that involves one or more claims and justifications for the claim(s), and argumentation is the process by which such texts are produced, critiqued, or refined (Sampson & Clark, 2008).

To guide data analysis and interpretation, this study used a Toulmin-inspired framework that is similar to frameworks adopted by a number of other researchers in science education (e.g., McNeill, González-Howard, Katsh-Singer, & Loper, 2016; Osborne et al., 2004; Sampson & Clark, 2009). Toulmin's (1958) model of an argument has been widely adopted in research on argumentation. Yet, limitations of analyzing students' arguments/argumentation with it have also been recognized (Kim & Roth, 2014). Because this study is conducted in an elementary science classroom, the argumentation taking place there is simpler in structure than that in Toulmin's model (which includes claim, grounds, warrants, backing, qualifiers, and rebuttal). Therefore, to avoid the inconsistencies and difficulties of analyzing and coding elementary students' discourse with Toulmin's initial model, I found it helpful and necessary to modify the model to be more appropriate to the specific research context in this study, which is a grade 5/6 science classroom. Specifically, I turned to the Alberta science curriculum for information about student performance expectations related to argument/argumentation at the elementary level. The current science program of studies for grades 1 to 6 (Alberta Education, 1996) and the draft kindergarten to grade 4 science curriculum[1] (Alberta Education, 2018) were taken as references. Even though these documents do not use the exact words *argument* or *argumentation*, argumentation is included and emphasized in the Alberta elementary science curricula. In the draft kindergarten to grade 4 science curriculum (Alberta Education, 2018), one of the guiding questions for grade 4 science learning is "How can engaging in scientific inquiry enable us to produce *evidence* to support explanations of scientific phenomena?" (p. 8). In the current science program of study

[1] At the time of writing this dissertation, the new curriculum is only available from kindergarten to grade 4.

for grade 1 to 6 (Alberta Education, 1996), “critical-mindedness in examining *evidence* and determining what the *evidence* means” and “a willingness to use *evidence* as the basis for their conclusions and actions” are clearly stated as the learner expectations for grade 5 and 6 students (B.24 and B.30). To be specific, students at this level (i.e., grades 5 and 6) are supposed to recognize, identify, provide, describe, demonstrate, interpret, and examine evidence to support knowledge claims or refute alternative ideas (Alberta Education, 1996). Besides recognizing (or identifying) and providing (or describing, demonstrating) evidence, students are also supposed to interpret and examine evidence in light of how the evidence is related to claims. In other words, they are expected to use scientific reasoning as well, while they are supporting or refuting an explanation for a phenomenon or a solution to a problem. Given these stated expectations, I modified Toulmin’s (1958) model and identified the structure of a scientific argument as consisting of three interrelated components: claim, evidence, and reasoning. I referred to other elementary science programs, such as BC’s (new) grade 5 and 6 science curriculum (British Columbia Ministry of Education, 2016) and the Next Generation Science Standards (NGSS) from the United States (NGSS Lead States, 2013), to make sure this structure of argumentation was appropriate for exploring whether fifth- and sixth-graders’ argumentation was consistent with student performance expectations, and thus cognitive development, at this level. To summarize, in this study, I see the structure of a scientific argument consisting of a claim supported by evidence and reasoning. In what follows, I elaborate on the three components.

Claim. A scientific knowledge claim includes the solution, conclusion, or position taken through observations or discussion to answer a certain question. It is not just a statement of one’s opinions; instead, the claim is a tentative statement that provides an answer to a certain question and is supported by, and fits with, evidence (Sampson & Clark, 2009). Making a quality scientific claim that is appropriate (i.e., answers or addresses the question) and scientifically correct (McNeill, 2011) is not easy for students (Jeong, Songer, & Lee, 2007; Norton-Meier, Hand, Hockenberry, & Wise, 2008). Moreover, studies (e.g., Choi, Notebaert, Diaz, & Hand, 2010; Takao & Kelly, 2003) also report that when students construct or evaluate arguments, they usually focus on the correctness of the claim, rather than looking at the relationships among question, claim, and evidence.

Evidence. Evidence in its broadest sense includes anything such as measurement or observation that is used to support the validity or legitimacy of the claim (Sampson & Clark, 2009). Evidence is different from data. Data could be any information about the natural world, including, for example, measurement, observation, experience, knowledge, or information from a book or media. Once data are related to a claim (to back it up or refute it), the data become evidence (supporting the claim or the counterclaim respectively). Strong evidence can sufficiently and appropriately support and be used to readjust the claim to make it valid (Bell & Linn, 2000; Jeong et al., 2007; McNeill et al., 2006; Peker & Wallace, 2009; Sandoval, 2003). *Sufficient*, in this context, means to provide enough data to support and determine the claim. *Appropriate* signifies data that are relevant and trustworthy to determine, support, and make the claim (Kim & Roth, 2014). Research has shown that students often have difficulty identifying and utilizing evidence, especially with regard to relating evidence to their claims (Anthony & Kim, 2014; Clark & Sampson, 2008). In addition, it has also been reported that students tend to draw on personal views or beliefs to explain phenomena, rather than using the data at hand as evidence to support claims (Chinn & Brewer, 1993; Sampson, Grooms, & Walker, 2011). When students use evidence, they usually prefer empirical evidence to other types such as hypothetical evidence or inference to support their claims (Kelly, Druker, & Chen, 1998; Lehrer & Schauble, 2006). Moreover, compared with secondary students and adults, younger learners (preschool and elementary levels) exhibit less "critical examination of any existing data or evidence that conflicts with their claims" and prefer positive data (Kim, 2016, p. 53).

Reasoning. Reasoning is the justification explaining how the evidence supports the claim (Sampson et al., 2011). The reasoning component of the framework indicates that an argument needs to include a rationale that shows why the evidence supports the claim and why the evidence provided should count as evidence (Sampson & Clark, 2009). It has been reported that students tend to provide evidence without explicitly articulating their justification (Sandoval & Millwood, 2008). Regarding this, many scholars argue that students have difficulties in articulating their reasoning and making their reasoning clear in an argument (Erduran et al., 2004; McNeill et al., 2016; Jiménez-Aleixandre et al., 2000; Sandoval & Millwood, 2005). Taking the "social nature of justification" (p. 853) into account, however, Kelly et al. (1998) argue that students do not regularly describe evidence or articulate reasoning when it is "intersubjectively available and assumed to be understood" (p. 857). In other words, when argumentation or reasoning occurs "in the normal processes that constitute school science" (p. 853) such as the social context of a classroom, much of what students need to understand each other does not need to be stated explicitly. Therefore, when student argumentation is embedded in the social context (e.g., the science classroom in this study), reasoning, as a component of argument, might be either explicit or implicit. However, irrespective of whether the reasoning during evidence-based argumentation is explicit or implicit, it is helpful for students to have some knowledge about the evidence (e.g., what counts as evidence, what kinds of evidence are "good" or "better" than others to support the claims, and ways to find or produce valid or trustworthy evidence) while they are in the process of justification. According to Sampson and Clark (2009), to construct a quality argument, individuals must coordinate their understanding of the phenomenon under investigation with their understanding of what counts as a good argument, "what counts as sufficient or useful" and "what counts as convincing and persuasive *in science*" (p. 452, emphasis in original). In addition, for a quality justification, students also need to monitor their thinking process and task performance, for example, knowing whether the data make sense to them and can be interpreted to be evidence, whether their claim is well justified, and whether their argument is convincing. Both having knowledge about evidence and monitoring their own thinking belong to Mc-A (i.e., metacognition in the context of argumentation). That is, Mc-A could play an important role in students' reasoning. Moreover, regarding instructional support for reasoning, it has been found that teachers have difficulty assessing students' reasoning and determining appropriate instructional supports to help improve students' reasoning (McNeill et al., 2016). Thus, according to McNeill et al. (2016), "reasoning can be the most difficult structural component or aspect of argumentation for teachers to integrate into their classroom practice" (p. 265).

2.1.2 Different Kinds of Argumentative Practice

I notice and acknowledge that, in common usage, *argument* also refers to "the act or process of arguing, reasoning, or discussing" (Argument, n.d.). Accordingly, some research (e.g., Cavagnetto, 2011) does not distinguish between these two terms (i.e., argument and argumentation). In my study, I wish to distinguish the artifact from the process, because my research has a particular focus on the process of how students participate in argumentation, and variations in the argumentation process might lead to variations in the final artifacts: arguments.

Studies in which argumentation is distinguished from argument and perceived as the process have different views, or at least different emphases, regarding what specific process(es) argumentation refers to or includes. For example, Ryu (2011) and Ryu and Sandoval (2012) use argumentation specifically to refer to "the process that produces the . . . argument" (Ryu & Sandoval, 2012, p. 490); that is, argumentation in their studies means the process of argument construction. Chen et al. (2016) and Chen, Hand, and Norton-Meier (2017), in their research on student scientific argumentation, investigated how students construct and critique arguments. In other words, even though they did not specifically limit what processes were included in argumentation, argumentation in their study consisted of both the process of argument construction and argument evaluation. Kim (2016) and Kim and Pegg (2019) explored student scientific argumentation with a particular emphasis on its dialogical characteristics or aspects, focusing on how argumentation emerges and develops within classroom conversations between students and their peers or their teachers.

In my study, argumentation, as the argument-related process, includes all three of these kinds of practices: argument construction, argument evaluation, and argumentative dialogue that takes place within interpersonal classroom conversations. Argument construction in this research refers to the process of building, developing, and/or strengthening an argument through, for example, searching and weighing evidence and connecting evidence to the claim. Argument construction also includes collecting multiple individual arguments, for example, into positions, which are organized groups of arguments designed to support a possible decision outcome (e.g., "NASA should approve and buy my technology."). Argument evaluation in my study refers to the process of assessing arguments, an individual argument, or an aspect of an argument for the purpose of constructing a stronger case or criticizing an opponent's case. By argumentative dialogue, I particularly mean the argumentative discourses that take place during classroom interpersonal conversations, such as ones between students and their peers or students and their teacher.

In summary, argument in my study includes three elements—claim, evidence, and reasoning—and refers to the artifact resulting from a cognitive and interactional process that I call argumentation. Argumentation, or argumentative practice, in my study is the process or endeavour by which arguments are produced, critiqued, or refined. Argumentation in this study is an argument-related social and cognitive practice and includes argument construction, argument evaluation, and argumentative dialogue.

2.1.3 Scientific Argumentation: A Cognitive & Social Process

Argumentation as a cognitively demanding process. Argumentation is a cognitive task involving cognitive skills. As a cognitive process, argumentation involves individuals' internal processes of thinking to reach a justified position. According to Kuhn (2010),

> even in the simplest case . . . of dyadic discourse with a single interlocutor, the arguer must simultaneously process the other's contribution and anticipate his or her own response to it and do so successively over what may become an extended sequence of turn-taking. Moreover, each contribution to the discourse disappears as soon as it is spoken. Any representation of previous contributions must be constructed and maintained by the arguer, posing a further cognitive burden. (p. 813)

As a cognitive task, argumentation includes both the cognitive level and the metalevel, that is Mc-A in this study. The cognitive level "involves cognitive skills that support the execution of argumentation" (Iordanou & Constantinou, 2015, p. 283). Activities such as interpreting data as evidence and backing up claims with evidence belong to this cognitive level. Being aware of what counts as evidence and when and why to present evidence and then consciously employing that awareness to modify one's own thinking and corresponding cognitive activities or behaviours are exemplars of Mc-A, which is discussed in detail in the next section.

Argumentation as/in/for social relation. Even though I acknowledge that argumentation is a cognitive process involving an individual's cognitive skills, it cannot be reduced to individualized knowledge or skills. In other words, it cannot be understood *merely* as cognitive skills. Many scholars who share this idea argue that argumentation is a social practice (e.g., Kim, 2016; Kim & Roth, 2014; Ryu & Sandoval, 2012), highlighting that it is directed to other people in order to reach an agreement by "putting forward a constellation of propositions intended to justify the standpoint before a rational judge" (van Eemeren et al., 1996, p. 5). In this study, I explore student argumentation in a classroom setting; that is, scientific argumentation in my study is embedded in the social context, from which it cannot and should not be separated. Therefore, as well as conceptualizing argumentation as a cognitive activity, I also see argumentation as an endeavour with a social element at its core. Specifically, I adopt the view of "argumentation as/in/for dialogical relation" proposed by Kim and Roth (2014, p. 301). According to them, "argumentation first exists *as* dialogical relation, for participants who are *in* a dialogical relation with others, and who employ argumentation *for* the purpose of the dialogical relation" (p. 301, emphasis in original). Kim and Roth further argue that argumentation refers to the confrontation of different ideas in a communicative exchange between two or more people or the confrontation of ideas in the inner speech of a single person. Hence, it is not a juxtaposition of logically contradictory relations that makes argumentation. Instead, argumentation exists as social or dialogical relations, which exist when different ideas become statements or assertions expressed in discourse. Seeing argumentation, including its emergence and development, as/in/for social relations also encourages efforts to explore argumentation to focus on "think-*ing* and reason-*ing* relations with others (other participants or other different ideas)" (p. 302, emphasis in original), that is, the process of argumentation, which is the focus of this study.

In sum, based on the aforementioned discussion about the nature of argumentation, in this study, argumentation is understood and studied as a form of social practice and, simultaneously, as a cognitive activity involving cognitive skills. Even if some scholars (e.g., Ryu, 2011) argue that these two perspectives (i.e., argumentation as social practice and argumentation as a set of cognitive skills) conflict with each other, in this study, I conceive of them as complementary. Integrating these two perspectives may enrich the understanding of argumentation. In this study, argumentation is embedded throughout the inquiry as students generate questions, collect data, interpret data into evidence, and construct and critique claims based on evidence and through social interactions with their teacher and peers. In other words, learning scientific argumentation occurs by using scientific argumentation in an investigative and social context to learn science (Cavagnetto, 2010; Kim & Roth, 2014; Kuhn et al., 2013).

2.1.4 Goals and Norms of Scientific Argumentation

Many scholars argue that, over an extended period, people who participate in a community identified by joint activities come to share a set of standards and values that shape the behaviours central to the activity (Driver, Newton, & Osborne, 2000; Ford & Forman, 2006; Kuhn, Wang, & Li, 2010; Kuhn et al., 2013; Ryu & Sandoval, 2012). Therefore, argumentation in school science, which is a kind of social practice, implicates not only competences or skills but also standards and values. Those standards and values are usually represented as norms and goals of argumentation (Kuhn et al., 2013). After reviewing a number of studies that reported limited or no success for improving students' scientific argumentation, Sampson and his colleagues (Sampson & Clark, 2009; Sampson et al., 2011) proposed that the mismatch between instructional support for students' argumentation and the unsatisfying outcomes resulted from students not understanding the goals and norms of scientific argumentation. Thus, facilitating students' understanding of the goals and norms of argumentation and employing those understandings to improve their argumentation abilities holds pedagogical significance. In this section, I review the goals and norms of scientific argumentation proposed by various scholars in the literature.

The goals of classroom argumentation. According to Kuhn (2010), of a number of theorists who have undertaken to characterize the goals of argumentation, one very commonly cited is Walton (1989). Walton (1989) identifies three main goals of argumentation "from the point of view of informal logic and critical thinking" (p. 174). The first is to persuade, that is, "the goal of each participant is to persuade the other participant of the acceptability of a specific proposition" (p. 174). The second is "to obtain further knowledge in a particular area, or on a topic . . . seek[ing] proof or evidence, or the establishment of a conclusion based on given evidence which is accepted in a field of inquiry at the original situation" (pp. 174–175). The third is for the arguer to maximize their own interests to get the "best deal" possible. Walton's ideas are about argumentation in general. When we consider the scientific argumentation taking place in classrooms, the first two goals, which are also argued in recent literature (e.g., Ryu & Sandoval, 2012), are more relevant and appropriate. It is widely accepted in the literature that the aim of classroom scientific argumentation is to persuade others to reach an agreement or consensus on a particular topic (Iordanou & Constantinou, 2015; Kuhn, 2010; Kuhn et al., 2013; Ryu & Sandoval, 2012). Through that goal-directed argumentative practice, students, as active agents, are supposed to clarify, critique, construct, and revise their ideas and then "obtain further knowledge in a particular area or on a topic" (Walton, 1989, p. 174). Understanding the aforementioned goals is believed to be essential for students' scientific argumentation; however, students usually lack such understanding (Sampson et al., 2011). Students' awareness and reportable understanding or knowledge of the goals of argumentation, as well as the conscious employment of those understandings, are included as important components of Mc-A in this study.

The norms of classroom argumentation. Besides summarizing the goals of argumentation, Walton (1989) also emphasizes the importance of argumentation norms by arguing that there should be a "relatively simple but precise set of rules" regarding how argumentation ought to be (p. 170). In the field of science education, with the recognition of the importance of argumentation norms, scholars try to summarize the specific norms of argumentation in the classroom. Michaels et al. (2008) refer to "accountable talk," by which they mean "reasoned discussion in the classroom" (p. 285), to represent their interpretation of the argumentation norms. According to them, accountable talk in the classroom encompasses three broad dimensions: accountability to the learning community, in which students listen to and build their contributions in response to those of others; accountability to accepted standards of reasoning, emphasizing logical connections and the drawing of reasonable conclusions; and accountability to knowledge, that is, discourse is based explicitly on facts, written texts, or other public information (Michaels et al., 2008). Those three accountabilities are also discussed by other scholars using alternative terms: social norms for the first accountability (Kelly, 2008; Lemke, 1990) and epistemic norms for the last two (Driver et al., 2000; Duschl & Osborne, 2002; Kuhn et al., 2013; Ryu & Sandoval, 2012).

Many scholars place special emphasis on the epistemic norms of argumentation, arguing that engaging in science argumentation requires students to appropriate epistemic norms or criteria to construct and evaluate scientific arguments. Those epistemic norms are concerned with the process of generating and validating scientific knowledge, that is, that which can be counted as legitimate in the scientific community, including the questions that need to be answered, the accepted methods to be used, and the data appropriate to be collected and interpreted (Ryu & Sandoval, 2012). Among all the epistemic norms for engaging in argumentation, specifically constructing scientific arguments, Ryu and Sandoval (2012) focus on the following four, which they consider "central to understanding scientific argumentation" (p. 494) and appropriate and important for elementary students (fourth graders) to learn and develop:

(1) *Causal structure*: Science is aimed at understanding the causes of natural phenomena. Consequently, students have to know that a scientific argument should contain causal claims.

(2) *Causal coherence*: Many, if not most, scientific arguments advance chains or networks of causal inferences. These chains have to cohere into a sensible overarching narrative.

(3) *Citation of evidence*: Claims are made about data; consequently, a good argument cites the data that claims are meant to explain.

(4) *Evidentiary justification*: A crucial element of an argument is the asserted relationship between claims and evidence. Good arguments explicate and justify these relationships. (Ryu & Sandoval, 2012, p. 494)

According to Ryu and Sandoval (2012), it is widely supported that understanding these epistemic norms of scientific argumentation can lead students to understand the epistemological bases of scientific practice.

Concerning the social norms of argumentation, which are the "unwritten rules" (Lemke, 1990) of classrooms or the "accountability to the learning community" (Michaels et al., 2008), Kelly (2008) has listed and elaborated the following seven norms, which he believes are important for students in a classroom: (a) make your ideas explicit in public; (b) listen to each other's opinions; (c) require or present all empirical available data for supporting claims; (d) require or present explicit justification; (e) challenge others' opinions by helping others improve their opinions or by providing an alternative opinion; (f) accept others' criticism; and (g) do not take others' comments as a personal attack. Even though Kelly (2008) refers to these norms as social norms, the third and fourth ones, highlighting that scientific arguments need to be supported by empirical evidence and that students need to explicitly explain how the evidence is related to the claims, are referred to as epistemic norms by Ryu and Sandoval (2012), as mentioned.

Distinguishing those categories is not the purpose of this study. What interests me is the processes of how students come to realize and perceive those norms, if they can, and consciously employ those norms to regulate their thinking and doing during argumentative practice. Limited research has investigated these processes. Students' awareness and reportable understanding (or knowledge) of the argumentation norms and conscious employment of those understandings to regulate their argumentative practice are also included as important components of Mc-A in this study.

How students perceive and appreciate goals and norms of argumentation. Ryu and Sandoval (2012) and Sampson et al. (2011) argue that students not understanding the goals and norms of scientific argumentation is the main reason for the limited success or failure of various instructional supports for improving argumentation. Kuhn (2010) explains students' understandings of the goals and norms of argumentation as a developmental issue, arguing that "as well as anticipating developmental differences in execution of the procedural or strategic aspects of discourse, there are also likely to exist developmental differences in this meta-level understanding of goals and purposes" (p. 813). However, in what way students come to understand the goals and norms of argumentation over time and how the perceived goals and norms are related to students' performance in argumentation are not fully clear. Ryu and Sandoval (2012) reported that students (third- to fourth-graders) were capable of refining "what counted as persuasive and the means to persuade" (p. 514), as well as norms related to the use of evidence. They argue that students' sustained engagement in argumentation and active and intimate involvement in generating and negotiating specific norms contribute to this refinement. Kuhn and her colleagues (2013) analyzed middle school students' "meta-talk" (talk about the discourse, distinguished from talk about the topic) that took place simultaneously during their paired argumentation. They reported that through their meta-talk, students developed some norms regarding argumentation, which resulted in the improvement of their arguments. Those norms had social aspects (e.g., "staying on topic"), and epistemic aspects (e.g., "key norm pertained to the role of evidence in argument"; p. 473).

Therefore, the aforementioned two studies suggest that (1) elementary students are capable of perceiving both the goals and norms of argumentation and of expressing and communicating with peers about their understandings of the goals and norms; (2) students' understandings of the goals and norms of argumentation might affect or influence their performances in argumentative practices; and (3) sustained engagement in and active reflection on argumentation could be potential ways to facilitate students' perception and appreciation of the goals and norms of argumentation. These findings informed the research design of this work. These studies, even if rather scattered, supported my expectation that the research design of my work to explore students' Mc-A while they were engaging in and encouraged to think and discuss about their argumentative practice was going to be feasible and potentially fruitful.

2.2 Metacognition in the Context of Argumentation (Mc-A)

This study aims to explore students' Mc-A (i.e., metacognition in the context of argumentation) in the elementary science classroom setting. Therefore, it is necessary to understand metacognition in general first, and then embed it into the specific context: scientific argumentation in the elementary classroom. Metacognition has been supported in the field of science education as a key component of students' learning of science, especially self-regulated science learning (Thomas, 2012), yet, metacognition itself is a fuzzy construct with various definitions in the literature (Thomas & McRobbie, 2013). In the next sections, I review the definitions of metacognition and explain the stance adopted in this study, and then describe how Mc-A and its components are defined in this study.

2.2.1 Metacognition: With Knowledge and Regulation Aspects

Conceptualizations of metacognition in the literature have in common that they take the perspective of "higher-order cognition about cognition" (Flavell, 1979; Nelson, 1996). According to Flavell (1976), metacognition refers to one's knowledge concerning cognitive processes and products or anything related to them, and "the active monitoring and consequent regulation and orchestration of these processes in relation to the cognitive objects or data on which they bear, usually in the service of some concrete goal or objective" (p. 232). Brown (1987) further introduces metacognition into educational environments. Echoing the key ideas of Flavell, Brown states that metacognition comprises two interacting components: *knowledge of cognition* and *regulation of cognition*. Brown's idea, which was produced to be used specifically with reference to the educational environment, has been further developed by many researchers in the field of education (e.g., Schraw, 1998; Thomas & McRobbie, 2001).

Later attempts to conceptualize and explain metacognition retain the tenets of the seminal work of Flavell (1976, 1979) and Brown (1987), yet reflect some subtle changes. For example, some scholars (e.g., Anderson & Nashon, 2007; Nielsen, Nashon, & Anderson, 2009) argue that besides the knowledge about cognition (or metacognitive knowledge) and regulation of cognition (or metacognitive regulation or skill), *metacognitive awareness* should be added as a third component. In the literature, however, there is a parallel view of metacognitive awareness. In the widely adopted instrument the *metacognitive awareness inventory* (MAI) developed by Schraw and Dennison (1994), metacognitive awareness means that students are aware of their knowledge about cognition and the regulation of cognition in which they are engaging. In that self-reported inventory consisting of 52 items, 17 of them are about knowledge about cognition and the other 35 are about the regulation of cognition.

Besides the main components of metacognition, later scholars proposed subcomponents of metacognition. Regarding metacognitive knowledge, some scholars (e.g., Whitebread et al., 2009) follow Flavell's (1979) subdivision of *person*, *task*, and *strategy* categories. Other scholars (e.g., Schraw, 1998; Thomas & McRobbie, 2001), based on the idea of Brown (1987), further divide metacognitive knowledge into *declarative*, *procedural*, and *conditional* knowledge. In relation to the subcomponents of metacognitive regulation, various ideas exist in the literature as well. For example, Schraw and Dennison (1994) argue that metacognitive regulation includes *planning*, *information management*, *comprehension monitoring*, *debugging*, and *evaluation*. Anderson and Nashon (2007) state that it includes *planning*, *monitoring*, *control*, and *evaluation*. And, in the model of metacognition proposed by Nelson and his colleague (Nelson & Narens, 1990, 1994; Nelson, 1996), *monitoring* and *control* are the two main ways of regulating cognition.

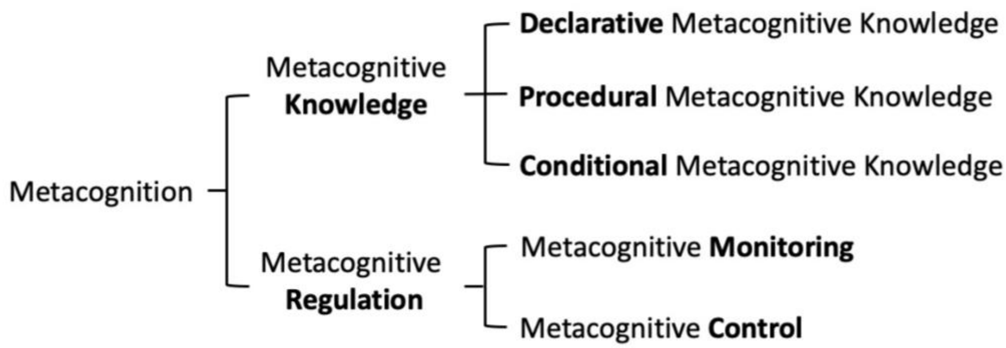


Figure 2.1 Components and subcomponents of metacognition in this study.

Based on reviewing the components and the subcomponents of metacognition in the literature, I limit how metacognition is understood in this work (shown above in Figure 2.1), including *metacognitive knowledge* and *metacognitive regulation* as the two components.

Metacognitive knowledge. Almost all the conceptualizations of metacognition include the knowledge aspect. In this study, metacognitive knowledge is described and understood through three categories: *declarative*, *procedural*, and *conditional* knowledge (e.g., Brown, 1987; Schraw, 1998; Schraw, Crippen, & Hartley, 2006; Thomas & Anderson, 2013; Thomas & McRobbie, 2001). Declarative metacognitive knowledge is about knowing that something is the case, for example, individuals' declaration of their definitions for learning, thinking, or other cognitive activities and their components, or one's knowledge in relation to cognition or people as cognitive processors. Procedural metacognitive knowledge relates to individuals' knowledge of how to perform cognitive activities and how they do so. Conditional metacognitive knowledge relates to students' understanding of both the value and the limitations of their procedural and declarative knowledge, knowing when and why to employ them, and why it is important to do so (Thomas & Anderson, 2013; Thomas & McRobbie, 2001; Whitebread et al., 2009). Despite metacognitive knowledge being dissected into those three distinct categories, interaction between the categories is evident and necessary. Moreover, as a kind of knowledge, metacognitive knowledge, similar to knowledge about the nature of the physical world, can be actively constructed and conceptually changed (Thomas & McRobbie, 2001) and has a socially mediated nature as well (Efklides, 2009; Goos, Galbraith, & Renshaw, 2002; Hogan, 2001; Iiskala, Vauras, & Lehtinen, 2004; Iiskala, Vauras, Lehtinen, & Salomen, 2011; Thomas, 2002).

Metacognitive regulation. In the literature, metacognitive regulation is also named by other scholars as *metacognitive skill* or *regulation of cognition*. According to the original definition of metacognition proposed by Flavell in 1976, metacognitive regulation, as a key aspect of metacognition, refers to the active monitoring and consequent control and orchestration of the processes in relation to cognitive objects. Even though some later scholars (e.g., Anderson & Nashon, 2007; Schraw, 1998; Schraw & Dennison, 1994) have tried to enrich the meaning of metacognitive regulation by adding more components into it, *monitoring* and *control* are still the most critical processes, emphasized in most of the fundamental conceptualizations of metacognition, such as Brown (1987), Flavell (1976, 1979) and Nelson and Narens (1990, 1994). In my work, I took this idea. That is, metacognitive regulation in this study includes *metacognitive monitoring* and *metacognitive control*.

Metacognitive monitoring refers to individuals' keeping track of their own thinking and learning processes by ensuring that things make sense within the accepted cognitive frameworks and knowledge schemata. Metacognitive control refers to individuals' conscious adjustment and executive control of one's own thinking and learning processes (Anderson & Nashon, 2007; Iiskala et al., 2004, 2011; Whitebread et al., 2009). Many studies support the notion that metacognitive monitoring and control have a very close relationship with students' learning (e.g., Azevedo, Cromley, & Seibert, 2004; Georghiades, 2006; Goos et al., 2002).

Concerning metacognitive awareness, in this study, I share the view of Schraw and Dennison (1994). That is, metacognitive awareness refers to students' awareness of the metacognitive knowledge they are holding and the metacognitive regulatory processes they are engaging in. Hence, metacognitive awareness is not separately listed as an aspect. Only metacognitive knowledge and regulation processes come into students' consciousness. That is, students are aware of and can consciously report (and apply) those knowledge and regulation practices, thus they can be called metacognitive knowledge and metacognitive regulation.

Thus far, this part has discussed how metacognition (in general) is understood in this study. This study took place in an elementary science classroom and focuses on students' argumentation. Hence, it is necessary to situate metacognition in the classroom scientific argumentation context. In what follows, I describe how Mc-A (i.e., metacognition in the context of argumentation) is defined in this study through explaining the knowledge and regulation aspects of Mc-A, namely metacognitive knowledge specific to argumentation (McK-A) and metacognitive regulation in the context of argumentation (McR-A).

2.2.2 Metacognitive Knowledge Specific to Argumentation (McK-A)

Metacognitive knowledge encompasses general knowledge, such as knowledge about people as learners, which is applicable to all cognitive enterprises. Besides general metacognitive knowledge, argumentation, as a series of higher-order cognitive actions, has its own unique metacognitive knowledge (i.e., McK-A in this study). Based on the definition and categories of metacognitive knowledge discussed previously, McK-A can be also understood through those three interrelated categories: declarative, procedural, and conditional. Specific descriptions and examples of each category are outlined in Table 2.1.

As stated previously, argumentation norms are mainly about how to perform argumentation, and goals of argumentation are related to when and why to perform argumentation. Therefore, through situating and understanding metacognitive knowledge in the argumentation context, I consider students' knowledge of the norms and goals of argumentation to be included in procedural and conditional McK-A respectively.

Table 2.1 *Categories, Description, and Examples of McK-A*

	Declarative McK-A	Procedural McK-A	Conditional McK-A
Description of the three categories of McK-A	Students' conscious, reportable, and applicable knowledge of ❖ their conceptions or beliefs of argumentation, components and products of argumentation; ❖ their personal abilities in argumentation.	Students' conscious, reportable, and applicable knowledge of ❖ how to perform or engage in argumentation; ❖ strategies related to argumentation; ❖ norms of argumentation.	Students' conscious, reportable, and applicable knowledge of ❖ when and why to engage in argumentation, i.e., goals of argumentation; ❖ the value and limitations of procedural knowledge regarding different contexts.
Examples of the three categories of McK-A	Students are aware of and can report and apply ❖ their knowledge of what an argument or argumentation is; ❖ their strengths or weaknesses in argumentation.	Students are aware of and can report and apply ❖ what they know about how to engage in argumentation; ❖ what they know about the norms of argumentation.	Students are aware of and can report and apply ❖ what they know about why argumentation is important and why to perform argumentation.

2.2.3 Metacognitive Regulation in the Context of Argumentation (McR-A)

Metacognitive regulation in the context of argumentation (McR-A) also includes both metacognitive monitoring and metacognitive control (shown below in Table 2.2). The description of those two metacognitive processes is adapted from previous empirical studies on students' metacognition, including Anderson and Nashon (2007), Iiskala et al. (2004), and Whitebread et al. (2009), with some revisions made in accordance with the particular context of this study: argumentation in the elementary science classroom.

Table 2.2 *Categories, Description, and Examples of McR-A*

	Metacognitive Monitoring in McR-A	Metacognitive Control in McR-A
Description of McR-A	Students consciously ✓ monitoring and keeping track of their own thinking during argumentation; ✓ continually assessing their own comprehension.	Students' conscious ✓ adjustment or control of their own thinking processes during argumentation.
Examples of McR-A	Students consciously monitor: ✓ whether or not other students' claims/arguments make sense to them; ✓ whether or not their own or others' argument constructing is appropriate; ✓ whether or not they comprehend others' arguments; ✓ whether or not they are convinced.	✓ After realizing that the current way of thinking does not work well, students consciously make adjustments.

Usually, metacognitive monitoring and metacognitive control are connected with the metacognitive knowledge held by learners. Take the metacognitive monitoring in McR-A, for example, monitoring "what" during argumentation would be related to students' McK-A. For example, if students know and are aware of the importance of evidence (i.e., declarative McK-A), they would monitor whether their opponents provide evidence or not; if so, they would further monitor their comprehension of opponents' evidences to prepare their own responses.

2.2.4 The Need to Empirically Explore Mc-A

As discussed previously, the importance of metacognition to various aspects of students' science learning, such as conceptual change and understanding the nature of science, has been recognized. In terms of Mc-A and students' scientific argumentation, even though there is little empirical research specifically on this matter, many scholars (e.g., Duschl, 2008; Garcia-Mila & Anderson, 2007; Jiménez-Aleixandre, 2007; Zeidler & Sadler, 2008; Zohar, 2007) have proposed the importance of metacognition (i.e., Mc-A) for scientific argumentation in various ways. For example, in a book chapter "Cognitive Foundations of Learning Argumentation," Garcia-Mila and Anderson (2007) argue that "metacognitive competencies [are] required for the conscious differentiation and coordination of theory and evidence. When individuals lack . . . [metacognition], they tend to merge theory and evidence into a single representation of the way things are" (p. 38). Likewise, Jiménez-Aleixandre (2007) outlines "the underlying design principles of classrooms seeking to promote argumentation . . . around six main issues: role of students, role of teacher, curriculum, assessment, metacognition, and communication" (p. 95), and suggests that "involving students in metacognitive thinking" will effectively promote student argumentation (p. 111).

Despite the importance of metacognition to scientific argumentation being *theoretically* suggested and widely accepted, there is little *empirical* evidence to support the importance of Mc-A. Little empirical research has specifically explored students' Mc-A, especially research taking place in authentic learning environments such as everyday classrooms and focusing on elementary students. Even if Mc-A was not their particular research focus, Kuhn et al. (2013) have provided some information related to middle school students' Mc-A, yet only the knowledge aspect of Mc-A. Having worked with middle school students, Kuhn et al. (2013) reported a causal relationship between students' metalevel understanding or knowledge of argumentation (i.e., the knowledge aspect of Mc-A, which I refer to as McK-A) and their argumentation skills. According to Kuhn and her colleagues, young adolescents' enhanced understanding of argumentation resulted in improved argumentation skills, such as addressing or weakening a counterclaim and supporting their claims with evidence. Kuhn et al. drew that conclusion mainly through examining students' final products of argumentation. To be specific, their study included an argument construction task and an argument evaluation task after the designed intervention, which was an extended engagement in argumentation with peers. Students' products of these two tasks were analyzed to measure their knowledge of argumentation and their argumentation skills. Then, results of the measurement were further compared between the intervention group and the control group. In other words, even though Kuhn et al. reported a causal relationship between students' metalevel knowledge of argumentation and their argumentation skills, which is important for future research around this topic, the process of how that relationship took place (i.e., how they related with each other) is still unknown. Therefore, more empirical studies that further explore Mc-A, especially the process of how Mc-A affects student argumentation, are much needed.

Thus far, this chapter has discussed components of metacognition, limited to what Mc-A refers to in this study and, based on the identified gap in the research literature, discussed the need to empirically explore students' Mc-A. With the aim to explore elementary students' Mc-A in a science classroom setting, this study employed argument-focused metacognitive scaffolds.

In the next sections, I review theories and research on scaffolding and discuss the use of metacognitive scaffolds to stimulate students' metacognitive experience. Finally, I describe the argument-based metacognitive scaffolds in this study.

2.3 Argument-Focused Metacognitive Scaffolding

2.3.1 Scaffolding

Besides the theories and studies on argumentation and metacognition, research on scaffolding also informed the research design of this study, in which I investigated students' Mc-A in the context of argument-focused metacognitive scaffolding in an elementary science classroom.

Wood, Bruner, and Ross (1976) originally introduced the term *scaffolding* in the context of adult-child interactions in which the more knowledgeable adult tutors the child to complete a task that the child would not be able to do on their own. With the help of scaffolds, learners can complete more advanced activities and engage in more advanced thinking (Bransford, Brown, & Cocking, 2000; McNeill et al., 2006). Although Wood et al. (1976) did not originally connect scaffolding to Vygotsky's (1978) zone of proximal development (ZPD), "a number of educational researchers since then have explicitly made this connection" (McNeill et al., 2006, pp. 159–160). This theory suggests that while learners may be at one specific level in their ability, they also have a potential level of ability which may be reached through interaction and guidance with a more knowledgeable other or peers or tools. The ZPD is the area between these two levels (Vygotsky, 1978). Stone (1993) argues that scaffolds allow students to achieve a higher level of capability within their ZPD. Moreover, McNeill et al. (2006) contend that for a scaffold to promote student capability, it needs to reside within a student's current ZPD. This assertion is reasonable because students will not be challenged to learn more if a scaffold provides too much information. Thus, the scaffold should provide the appropriate amount of information that allows the learner to progress. In other words, learners' cognitive abilities to process information should be taken into account when scaffolds are designed.

When Wood et al. (1976) proposed the term scaffolding, they also discussed that scaffolding should be a flexible process contingent on what a child knows and the characteristics of the learning task. This suggests that scaffolds should be adjusted over time rather than remaining constant, since students know more and more along the process of learning. Some studies based on Vygotsky's (1978) idea have echoed this. For example, in the 1980s, in their study of reciprocal teaching, Palincsar and Brown (1984) discussed Vygotsky's idea that at first the teacher or expert guides much of a child's cognitive activities, and over time, the child takes on more and more of those responsibilities, eventually performing the activity by themselves without the scaffolds. In a more recent study, McNeill et al. (2006) found that the "fading scaffolds in the instructional materials" that involved "less support over time" showed better results than continuous scaffolds to support students' construction of scientific explanations (p. 153). In other words, scaffolds help learners complete a task independently and as such should be adjusted, either faded or changed to have another focus, as learners develop their own understandings.

2.3.2 Metacognitive Scaffolds: Scaffolds to Stimulate Students' Metacognitive Experiences

Flavell (1987) discusses that, while we may be born with some metacognitive abilities, most of them can be taught and practiced. Since the majority of students do not spontaneously engage in metacognition, intentional facilitation or scaffolding is needed (Conner, 2007; Cubukcu, 2009). Extensive research has focused on developing scaffolds to facilitate students' metacognition through stimulating their metacognitive experience (Zohar & Barzilai, 2013), which refers to any conscious experiences related to cognitive endeavours or to metacognitive knowledge or regulation (Thomas, 2013; Thomas & McRobbie, 2001).

Thomas and colleagues have tried to develop and enhance student metacognition through “metacognitive conflict” (Thomas, 2012, p. 139). Thomas and McRobbie (2001) designed an intervention in a high school chemistry class, using the metaphor “learning is constructing” to engage students in thinking about what learning science is and to challenge their previous views about learning. In their later research, Thomas and McRobbie (2013) introduced a thinking framework, considering a chemical phenomenon “at macroscopic, molecular/sub-micro and symbolic levels” (p. 300), to high school students. With the introduction and use of this thinking framework, students’ existing frameworks were challenged. Studies (Thomas & McRobbie, 2001, 2013) employing this kind of scaffolding (i.e., metacognitive conflict) have reported improvements in students’ metacognition and science learning. Nevertheless, the requirements for teachers to adopt this metacognitive conflict approach might hinder its extensive usage (Thomas, 2012). For example, using this kind of approach requires not only in-depth understanding of the new thinking framework, as well as the difference between the new and the previous ones, but also a very good mastery of certain language with which teachers can communicate with their students about the relatively abstract thinking frameworks.

Besides the aforementioned approach (i.e., metacognitive conflict), various other scaffolds can be found in the literature to try to facilitate student metacognition, including, for example, using prompts, cues, and questions; group discussions of thinking and learning; reflective writing; teacher modelling; concept maps and other visual aids; and the use of software or technology-supported instruction to facilitate metacognition (Zohar & Barzilai, 2013). To stimulate students’ metacognitive experiences, these approaches either change the learning environment through, for example, posing metacognitive demands to students through prompts and questions, or provide metacognitive activities (e.g., reflective writing and teacher- or student-led discussion of thinking; Thomas, 2012). Usually, many of these approaches are employed together within a study. Many studies using this kind of scaffold report improvements in students' metacognition and learning (e.g., Conner, 2007; Davidowitz & Rollnick, 2003; Georghiades, 2004, 2006; Kipnis & Hofstein, 2008; Peters & Kitsantas, 2010; Shamir, Zion, & Spector-Levi, 2008).

2.3.3 Argument-Focused Metacognitive Scaffolding in This Study

A review of the literature reveals that, without particular scaffolds, students (especially younger learners, such as elementary students) usually do not spontaneously engage in argumentative practice, as research has found that they often have difficulty identifying and utilizing evidence (Anthony & Kim, 2014) and articulating justification (Erduran et al., 2004; McNeill et al., 2016); nor do they spontaneously involve themselves in metacognitive experiences (Thomas, 2012). Therefore, with the aim to explore students' Mc-A, this study specifically introduced *argument-focused metacognitive scaffolding* to the elementary science classroom (i.e., the research context of this study). In my study, argument-focused metacognitive scaffolding refers to scaffolding that aims to engage students in argumentation (i.e., the process of developing, revising, and evaluating an argument, which includes claim, evidence and reasoning as its components), and to stimulate their metacognitive experiences.

Many scholars (Gunstone, 1994; Thomas, 2012; Veenman, 2011; Zohar & Barzilai, 2013) have suggested that embedding metacognitive scaffolds within everyday science learning is important, because it increases the chance that students will be motivated to attend to the activities that are suggested to them, thereby also increasing the chances that their metacognitive experiences will be stimulated (Thomas, 2012). Following this suggestion, the argument-focused metacognitive scaffolds in this study were integrated into the everyday science classroom instruction throughout the entire research period and implemented whenever the teacher thought appropriate. Moreover, in alignment with the aforementioned literature on scaffolding, the argument-focused metacognitive scaffolding in this study was adjusted throughout the process of implementation in the classroom. (Scaffolds are described in detail in Chapter 3.)

2.4 Summary

This chapter summarized the main findings and gains from a review of related literature on argumentation, metacognition, and scaffolding, which constitute the theoretical grounds for this study. The literature review also helped define and limit the study's key terms (i.e., Mc-A, McK-A, McR-A, argument-focused metacognitive scaffolding). Moreover, through reviewing previous research, both on students' scientific argumentation and on metacognition, I identified the potential contribution of my work, which explores an issue (i.e., students' metacognition in the context of scientific argumentation in a classroom setting) argued to be important by many scholars, yet, which little empirical research has investigated. Researchers have argued the importance of Mc-A to students' engagement of scientific argumentation in terms of, for example, understanding the goals and norms of argumentation. Nevertheless, few empirical studies have specifically explored students' Mc-A, especially elementary students' Mc-A. Little information is available in the literature about, for example, what Mc-A looks like within various argumentative practices, how we can "see" it, and how it is involved in the process of argumentation. Given these gaps in the literature, in my study, I explored elementary students' Mc-A in a science classroom setting, aiming to answer two questions: (1) How is students' Mc-A involved in the argument construction, argument evaluation, and argumentative dialogue in science classrooms? and (2) How is the manifestation of students' Mc-A related to classroom interactions with the teacher, other students, and the researcher? In the next chapter, I describe how my research was designed to answer these two research questions.

CHAPTER 3

METHODOLOGY & METHODS

The purpose of this chapter is to establish the methodological framework for the study, as well as to describe the data collection and analysis procedures and discuss trustworthiness and ethics. In this chapter, I first reflect on some basic beliefs about the ontological and epistemological levels, then discuss the rationale for the use of qualitative case study to explore students' Mc-A (metacognition in the context of argumentation) in the science classroom setting. Next, I describe the setting and participants and provide detailed accounts of data collection and analysis procedures. Finally, I review criteria for assessing the trustworthiness of the findings and discuss ethical considerations.

3.1 Myself as a Researcher

The researcher's worldview that defines, for its holder, "the nature of the world, the individual's place in it, and the range of possible relations to that world and its parts" (Guba & Lincoln, 1994, p. 107) fundamentally influences how the researcher will interpret and explore the research topic. Hence, in this section, I reflect on some basic beliefs I hold as a researcher.

Situating myself within the social constructivist paradigm, I contend that reality is socially constructed, that there are different ways in which reality is constructed or conceived, and that those differences may well reflect different practical interests and traditions (Denzin & Lincoln, 1994, 2008; Merriam, 1998; Vygotsky, 1978). Pring (2000) states: "We do live in the world of ideas and how we see the world depends very much upon the ideas we have inherited," so "different social groups do, in important respects, conceive the world differently" (p. 253). I also contend that people construct their understandings of reality, and that those constructions of meaning are based on their interactions with their surroundings (Lincoln & Guba, 1985). That is, knowledge is created through those interactions (Guba & Lincoln, 1994). Accordingly, meaning or knowledge should not be described as objective. However, neither should it be described as absolutely subjective. Instead, during the construction of meaning, "objectivity and subjectivity need to be brought together and held together indissolubly" (Crotty, 1998, p. 44). As Crotty (1998) explains, "because of the essential relationship that human experience bears to its object, no object can be adequately described in isolation from the conscious being experiencing it, nor can any experience be adequately described in isolation from its objects" (p. 45). These are my basic beliefs, with which I explore students' Mc-A in the context of everyday science learning.

My basic beliefs determine how I interpret and explore my research topic: elementary students' Mc-A in the "real-life" science learning context of this study (Anderson, Nashon, & Thomas, 2009, p. 183). First, I adopt qualitative case study with descriptive and interpretive emphases (described in detail below) to explore this topic, since this methodology is consistent with my ontological and epistemological beliefs. Second, I acknowledge and appreciate that people such as young students and the teacher in my research think and learn (i.e., interpret the world and construct their knowledge) differently, thus, any findings or patterns presented in my study are merely about the participants in this research. Third, I try to describe the context (e.g., the curriculum, classroom environment, interactions between the teacher and students) with as many details as I can provide, as I contend that the context influences how students learn, think, and perform, thus the "complexity of the learning environment must be recognized and accounted for as much as possible" (Anderson et al., 2009, p. 183). Moreover, even if video cameras record what actually happens in the classroom, what students share with me in the interviews is influenced by their identities and experiences. (Video recording and interviews are two of the main data collection methods in this study that are described in detail in a later section.) Finally, I admit that all my interpretations, especially the interpretation of students' metacognition, which is a more mental activity, and even my descriptions are shaped by my experiences and identity, including my deep-seated belief that metacognition and argumentation are critical to science learning.

3.2 Qualitative Case Study

To answer the research questions, I framed my work as a qualitative case study. The purpose of a case study is to conduct "a concentrated inquiry" (Stake, 2000, p. 436), which is why I chose this as the methodology informing this study. According to Merriam and Tisdell (2015), the case is:

> a single entity, a unit around which there are boundaries. You can "fence in" what you are going to study. The case then, could be a single person who is a case example of some phenomenon, a program, a group, an institution, a community, or a specific policy. (p. 38)

Within this research, the case was a science class within an elementary school, including the teacher and her 18 students. This science class was a case example of the phenomenon (or subject) under investigation, that is, students' Mc-A in the context of argument-focused metacognitive scaffolding in classroom science learning.

Case study, according to Merriam (1998), "offers a means of investigating complex social units consisting of multiple variables of potential importance in understanding the phenomenon" (p. 41). Further, because it is "anchored in real-life situation, the case study results in a rich and holistic account of a phenomenon" (Merriam, 1998, p. 41). Thus, case study is considered appropriate for studying contemporary events which the researcher has little control over, such as the events taking place in a classroom, and when the focus of the investigation is the process of learning rather than the outcome. Therefore, case study is appropriate to achieve the research purposes of this study.

Moreover, “case study does not claim any particular methods for data collection or data analysis . . . any and all methods of gathering data, from testing to interviewing, can be used in a case study” (Merriam, 1998, p. 28). A multimethod approach fits well with studies in the field of argumentation (e.g., Hong et al., 2013; Kuhn et al., 2013; Lazarou, Sutherland, & Erduran, 2016) and metacognition (Anderson et al., 2009; Thomas, 2012) in science education.

Merriam (1998) argues that case study can also be described by the overall intent(s) of the study. Depending on the aims, a case study has both descriptive and interpretive aspects (Merriam, 1998). This research is descriptive because it aims to “present a detailed account of the phenomenon under study” (p. 38), which was elementary students’ Mc-A in the context of argument-focused metacognitive scaffolding in their science classroom. Merriam writes that descriptive case studies in education are useful for presenting “basic information about areas of education where little research has been conducted” (p. 38), such as students’ Mc-A. To further explore students’ Mc-A, in addition to including rich and thick description, I also used these descriptive data to interpret the processes of how students’ Mc-A manifested in classroom science learning and how students’ Mc-A was involved in various kinds of argumentative practice, “to illustrate, support, or challenge theoretical assumptions held prior to the data gathering” (e.g., the importance of metacognition for argumentation; p. 38). Seen from this perspective, this case study also has an interpretive aspect.

3.3 Setting and Participants

This section describes the setting and participants of this study to provide general information about the research context. The curriculum context, including the focused-activities and teacher's scaffolds, is described in detail in the next chapter.

This study took place in a combined fifth- and sixth-grade science classroom in a public elementary school in Edmonton, Alberta. The classroom was equipped with a projector, a smart whiteboard, and a computer with access to the internet. The school also provides students Google Chromebooks. When the teacher thought it was appropriate for the students to use these Chromebooks, she could sign on via the interschool system and get her students these laptops. The classroom had 19 students, and 18 of them agreed to participate in this study. The participants were 4 girls and 14 boys, 11 of whom were sixth-graders and 7 fifth-graders. The science teacher participating in this study, Ms. Bowen, had 10 years of teaching experience at the time of the study, with around 7 years teaching at this level (grade 5/6) in this school. The teacher was interested in learning and understanding how students learn. In her own words, "Whether students know the right answers is not important to me. What matters is how they [think], the thinking processes behind . . . and it is important that they do not only know the answers but also they . . . need to know *why*" (conversation with the teacher, 2018/02/12). Besides the science teacher, there was also an educational assistant in the classroom to assist two students with special needs.

3.4 Data Collection

3.4.1 Employing Multiple Methods for Data Collection

This study employed multiple methods for data collection. As Patton (2015) points out, "multiple sources of information are sought and used because no single source of information can be trusted to provide a comprehensive perspective" (p. 306). Employing multiple methods depends on the aim of collecting more relevant data on metacognition, particular Mc-A in this study. Because metacognition is a more "inner awareness or process" (White, 1988, p. 73, as cited in Thomas & McRobbie, 2001), difficulties arise in attempting to collect relevant data to demonstrate metacognition. Accordingly, echoing White (1998), Veenman (2005) stresses the potential of employing multiple methods, especially those using different types of instruments administered at different times in relation to the performance of the task. Numerous studies on metacognition have supported the use of multiple methods (e.g., Anderson, Thomas, & Nashon, 2009; Davidowitz & Rollnick, 2003; Efklides & Petkaki, 2005; Georghiades, 2006; Peters & Kitsantas, 2010; Sandí-Ureña, Cooper, & Stevens, 2011; Thomas & McRobbie, 2001).

The multiple-method approach also fits well with the qualitative case study methodology informing this study (Merriam, 1998). Therefore, in this study, multiple methods for data collection were employed. Specifically, to investigate students' Mc-A, data were collected through a variety of sources, including classroom observations, interviews, and students' writings. Table 3.1 below provides a summary of the various methods and the purposes of each one, and Figure 3.1 (shown below) shows an overview of the data collection in this study, as well as the outline of the research design, including focused activities and scaffolds, which are described in detail in the next chapter.

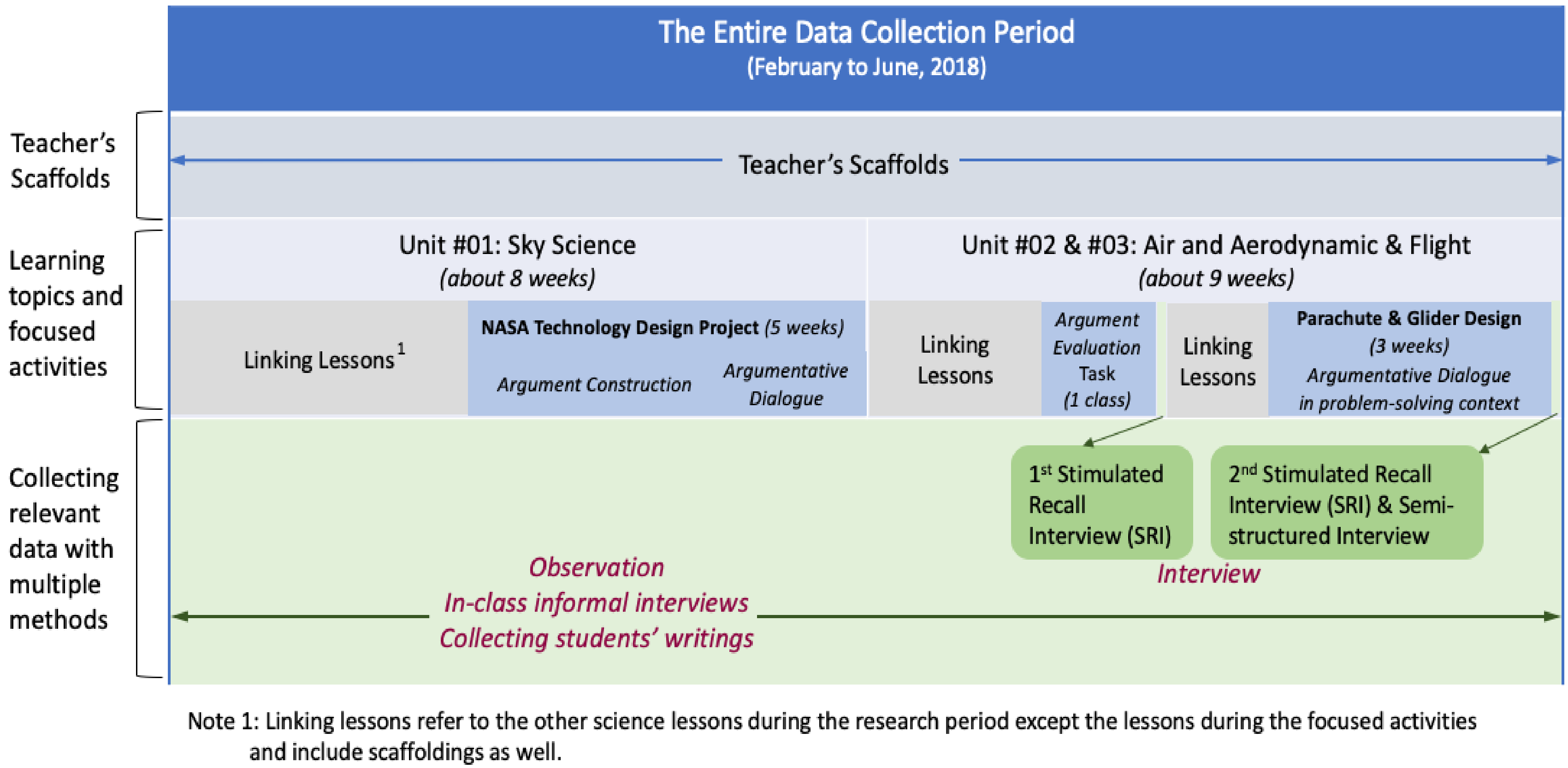


Figure 3.1 Overview of the focused lessons, scaffolds, and data collection in this study.

Table 3.1 *Data type, source, and purpose of the collection*

Methods	Data Source	Purpose of the Data Collection
Observation	Classroom Observation	-- To observe firsthand students' performances (on the cognitive level) in various kinds of argumentative practice -- To observe firsthand how students interacted with peers and the teacher -- To illustrate what the video camera or audio recorders cannot record in terms of the limitations of technology in a noisy classroom and what the researcher has seen and perceived (through field note-taking)
	Video/Audio Recordings	-- To access students' performances (on the cognitive level) in various kinds of argumentative practice -- To provide data on how students interacted with peers and the teacher -- To provide episodes for the SRIs
Interview	Stimulated Recall Interview (SRI)	-- To access student Mc-A (retrospective)
	In-class Informal Interview	-- To access student Mc-A (concurrent) (based on the researcher's on-site classroom observation)
	Semistructured Interview	-- To learn students' understandings of scientific argumentation, as well as their perceptions of the function of the argument-focused metacognitive scaffolds
Collecting Students' Writings	Argument Evaluation Task	-- To access students' understandings of argument/argumentation and argumentation skills -- To access student Mc-A -- To provide materials for the SRIs
	Other writings	-- To provide more supplementary information to understand student argumentation and their Mc-A

3.4.2 Observation

Classroom observation. In this research, I employed observation as one of the main methods of collecting relevant data. Observation is "the process of learning through exposure to . . . the day-to-day or routine activities of participants" (Schensul, Schensul, & LeCompte, 1999, p. 91), which in this study is science teaching and learning in the classroom setting. According to Merriam (2016), "observation is the best technique to use when an activity, event, or situation can be observed firsthand" (p. 139). Because observation takes place "in the setting where the phenomenon of interest . . . occurs," the "observational data present a firsthand encounter with the phenomenon of interest" (p. 137). In this study, even if students' Mc-A, which is an inner awareness or thinking process, usually cannot be observed directly, students' performances (on the cognitive level) in argumentation can be observed firsthand. Thus, one of the purposes of observation in this study was to gain a firsthand encounter with (Merriam, 2016, p. 137) students' performances in their argumentative practices. For this purpose, I was in the science classroom to directly observe the teaching and learning taking place there over the four months.

Regarding my role in the classroom, according to Gold's (1958) classic typology that offers a spectrum of researcher's stances while collecting information as an observer (i.e., complete participant, participant as observer, observer as participant, and complete observer), I identified myself as the observer as participant. That is, my observer activities were known to the teacher and students; participation in students' learning was secondary to the role of information gatherer.

No one can observe everything, especially in complex settings such as the classroom in this study. Therefore, I decided ahead of time to concentrate mainly on observing students' performances in various kinds of argumentative practice, including argument construction, argument evaluation, and argumentative dialogue. The coding framework for students' argumentative discourse (see below in Table 3.3), which is discussed in detail later in this section, was also used to guide my on-site observation to keep me focused on students' argumentation. With this coding framework as a guide, I focused on students' conversations, actions, and interactions during their classroom science learning. The teacher's scaffolds, the classroom environment (e.g., classroom setting, available technologies and resources), and other contextual factors (e.g., informal or unplanned activities) were also observed. In addition, following Merriam's (2016) suggestion about what to observe, I also paid attention to my own behaviours (i.e., what I said, what I did), how I as an observer affected the scene I was observing, and what thoughts I was having about what was going on. These thoughts, which Merriam (2016) calls "observer comments" (p. 142) and Patton (2015) calls "field-generated insights and interpretations" (p. 305), became an important part of my field notes. My field notes also included other information to capture what the video camera and audio recorders could not record due to the limitations of technology in a noisy classroom. (Classroom activities were also recorded and the video/audio recording is described in the next section.) I wrote up all the field notes either during the observation or as soon after the observation as possible.

In addition to providing a "firsthand encounter with the phenomenon of interest" (Merriam, 2016, p. 137), observation can also provide the researcher with "specific incidents or behaviors . . . that can be used as reference points for subsequent interviews," either formal or informal ones (p. 139). Merriam explains that "this is a particularly helpful strategy" for understanding ill-defined or complex phenomena, such as students' argumentation and metacognition in this study (p. 139). Due to this characteristic of observation, Merriam asserts, “in the real world of collecting data . . . informal interviews and conversations are often interwoven with observation” (p. 137), and this was the case in this research. In this study, along with the “specific incidents or behaviors” (Merriam, 2016, p. 139) I discerned during the classroom observations, I conducted in-class informal interviews with students to probe and understand their thinking processes behind these incidents and behaviours and to access their Mc-A. (These interviews are described in detail in section 3.4.3.)

Bernard (1994) writes, “Being [at] a site over a period of time familiarizes the observer to the community, thereby facilitating involvement in sensitive activities to which he/she generally would not be invited” (p. 142). Students’ Mc-A in this study is “sensitive” in nature, therefore, it was important and helpful for me to be persistently on the site, familiarizing myself with the research context, as well as familiarizing the teacher and students with my presence. Therefore, as shown in Figure 3.1, instead of starting with focused activities, the data collection in this study began with linking lessons, which I saw as the “entry” stage of collecting data through observation (Merriam, 2016, p. 142). (The research design and context, including descriptions of the focused activities, linking lessons, and scaffolds, are presented in the next chapter.) During this stage, I was prepared to answer and did answer students’ questions about my presence. When I first entered their classroom, after I introduced myself, I answered students’ questions, such as who I am, what I preferred they call me, why I was in their classroom, what I was going to do in their classroom, what I was going to do with my research, why I was setting up cameras in their classroom, how long and how often I was going to be in their classroom, and so on, to start building a trust relationship between myself and the research participants, especially the students. During the research period, I took Bogdan and Biklen’s (2007) suggestion that establishing and maintaining rapport by helping out on occasion, being friendly, and showing interest in participants' activities, whether or not they were closely related to my topic. It did not take long (around a week) before my presence was acknowledged with students' smiles, greetings, and active sharing with me what interested them.

Video/audio recordings. Even if I observed as intently as I could, tried to remember as much as possible, and then recorded in as much detail as possible what I had observed, the data collected through firsthand observation were still limited, especially when students were working individually or in small groups, since I could only observe one student or one group at a time. Therefore, to gather more relevant data, I also recorded all the science classes during the research period. To record students' classroom activities, there were four cameras and two audio recorders. When Ms. Bowen was introducing and explaining activities or leading a whole-class discussion, one camera was put in front of the classroom and the second was set in the back in order to capture all classroom interactions. When students were working in small groups, either getting feedback from the teacher during the argument construction activity or working in groups to design and improve their parachutes and gliders, each group had a camera or a voice recorder (there were five groups during the parachute and glider design, so one group had a voice recorder and the other four had cameras) to capture the group interactions.

Self-reflection on being the observer in the classroom. The classroom observation allowed me, as a researcher, to investigate the classroom discussions, the interactions among students and the teacher, and the way students participated in argumentation in a whole-class setting, in small groups, and individually. It also gave me opportunities to have in-class informal interviews with students regarding their inner thinking at that moment. However, while I was gathering informative data about the phenomena of interest (i.e., students' argumentation and metacognition in this study), I was (and am now) conscious that my presence as an observer was affecting and changing what was being observed. The presence of anyone (e.g., myself as the observer) or anything (e.g., interactions between myself and the students, the cameras I brought into the classroom) in a research environment is going to have some effect (Roach, 2014). At the very least, participants, both the teacher and students, who knew they were being observed would "tend to behave in socially acceptable ways and present themselves in a favorable manner" (Merriam, 2016, p. 148). The mere presence of myself as the observer in the classroom would also "affect the climate of the setting, often effecting a more formal atmosphere than is usually the case" (Merriam, 2016, p. 148). Therefore, I acknowledge that my presence as an observer in the classroom affected what I observed (i.e., students' performances in argumentation and their Mc-A). The question, then, is not whether the process of observing affected what I observed, but how, as the researcher, I can identify those effects and account for them in interpreting the data.

As mentioned previously, I identified my role in the classroom as *observer as participant* (Gold, 1958). Adler and Adler (1998) refer to this kind of observer as have a "peripheral membership role," which is different from having an active membership role (p. 85). In other words, using this method, researchers such as myself may have access to a wide range of information or data, but "the level of the information revealed is controlled by the group members being investigated" (Merriam, 2016, p. 145). This was another thing I needed to acknowledge as I collected data through observation.

Moreover, as with any other qualitative research method, the observer as the main research tool uses their own knowledge and expertise to interpret what they observe (Kawulich, 2005), as I did in this study. My observation was selective. What I paid special attention to and what received only passing attention were determined, not only by the research questions of this study, but also by my own knowledge and experiences. Therefore, I also acknowledge that my observation involved my subjectivity, rather than being absolutely objective or detached.

3.4.3 Interviews

It is not possible to observe everything by using classroom observation and/or video/audio recordings. We cannot observe feelings, thoughts, or how people interpret the world around them (Merriam, 2016; Patton, 2015), thus "we interview people to find out from them those things we cannot directly observe" (Patton, 2015, p. 426). Moreover, in a classroom setting, interviews can provide access to the context of students' actions (Seidman, 1998), and thereby provide me, as a researcher, with a way to understand the meaning of those observed students' actions better and from their perspectives (Kvale, 1996). Therefore, to access students' Mc-A, which is an inner thinking process or awareness that is usually difficult to observe directly, and to learn students' perceptions of argumentation and their teacher's scaffolds, I adopted interviews as another method for collecting relevant data.

Three kinds of interviews were used in this study: stimulated recall interview (SRI), in-class informal interview, and semistructured interview. The first two kinds of interviews were aimed at accessing students' Mc-A. Interviewing, as a method for collecting data on metacognition, has its own advantages as well as limitations. Thus, in what follows, I first discuss the advantages and limitations of interviews to explore students' metacognition. Then I describe how these interviews were conducted and offer my reflections on being the interviewer.

Accessing students' Mc-A with interviews. The challenge of developing assessment of or approaching metacognition has been well recognized and documented (Thomas & McRobbie, 2001). To collect relevant data, researchers have tried many methods (Anderson et al., 2009; Veenman, 2005). It is noteworthy that "each of these methods have inherent pros and cons"

(Anderson et al., 2009, p. 183). For example, studies have shown that questionnaires can be easy to administer to large groups of students to gather data on their metacognition, yet "scores on these questionnaires hardly correspond to actual [student] behavioral measures during task performance" (Veenman, Van Hout-Wolters, & Afflerbath, 2006, p. 9). Think-aloud protocols are more suitable for individual metacognition assessments (Anderson et al., 2009); however, they may prevent students from learning the present materials while they express their metacognitive opinions verbally (Akturk & Sahin, 2011). Likewise, interviews, which I adopted in this study to gather data on students' Mc-A, is a method that has its own strengths and limitations. The most important strength of interviews is that they can provide rich and highly qualitative data on students' metacognition from their own perspectives (Anderson et al., 2009). Moreover, interviewing offers the researcher opportunities to continue to ask further questions if an answer is incomplete (Veenman, 2005). However, according to Veenman (2005), when students are interviewed to report their thinking processes, it usually requires a reconstruction of or a reflection on these thinking processes. Such reconstructions or reflections may distort the thinking processes reported. Students might know more than they tell, and they sometimes tell more than they know (Veenman, 2005). Another issue that presents a challenge for self-report interviews is social desirability. Participants' responses may be affected by their own expectations and the perceived expectations of others, such as the interviewer (Thorndike, 2005). These are the limitations of interviews, which I need to acknowledge, as the method for collecting data on students' Mc-A in this study.

After reviewing methods for collecting data in studies on metacognition, Veenman (2005) described various methods in terms of their temporal relation to the performance of a task, that is, prospective (if administered before the task), concurrent (during the task), and retrospective (after the task) methods. He stressed the potential of employing methods that are administered at different times in relation to the performance of the task, echoing White's (1998) view that "good research on metacognition involves a battery of diverse but supportive measures" (p. 1211). Therefore, in this study, I adopted two kinds of interviews: SRI and in-class informal interviews, to gather data on students' Mc-A retrospectively and concurrently.

Stimulated recall interview (SRI). The main purpose of SRI in this study was to access students' Mc-A, which is an inner awareness or thinking process that is usually difficult to observe directly. As discussed above, a vital problem for retrospective interview as the method to gather data on metacognition "concerns the risk of memory failure and distortions due to [such as] the time lag between the actual performance of processes and verbal reports afterwards" (Veenman, 2005, p. 83). To deal with these potential "memory failures and distortions," I employed SRI. SRI has proven to be a useful method for circumventing the memory-failure or distortion problem (Veenman, 2005, p. 83). During the SRIs, students were invited to review an episode or episodes from the videotapes of their performance of a specific task and to reproduce their thought processes (Thomas & McRobbie, 2001; Veenman, 2005), followed by some questions regarding their thinking at that time. (How the episodes were chosen from the videotapes is discussed in section 3.5 "Data Analysis.") In addition to the episodes of their classroom activities, in this study, students' written argument evaluation tasks were presented to students for the SRI as well. Anderson and his colleagues (Anderson et al., 2009) have suggested that SRI has the potential to provide "an additional rich and highly qualitative means . . . to elucidate and understand the nature of the metacognition manifest among the participants and groups within which they [are] situated" (p. 185).

Moreover, with SRI as a method for collecting data on students' Mc-A, it is very important to have students feel safe and be willing to share their thinking processes with the interviewer. Therefore, building a trust-based relationship with the students was critical. To develop such relationship with students, I established and maintained rapport between myself and students by helping out on occasion, being friendly, and showing interest in students' activities, whether or not they were closely related to my topic (Bogdan & Biklen, 2007). In addition, I conducted the two rounds of SRIs in the middle and at the end of the data collection respectively, instead of at the beginning when the students and myself were not familiar with each other. All the SRIs with students started with casual talks about topics that they were interested in, and moved gradually to the questions related to their Mc-A. Students in this study were invited to participate in SRIs twice during the entire research period. The first round of SRI was after they completed the argument evaluation task. The other one was at the end of the data collection after they finished the parachute and glider model design and improvement (see Figure 3.1). Some examples of interview questions for the SRI are included in Appendix A.

In-class informal interview. In-class informal interview, as a method to gather data on students' Mc-A concurrently while they were engaged in their argument-related learning tasks, was also adopted in this study. As an "on-line" data collection method, in-class informal interviews allowed students to adequately report their thoughts as well as their actions (Veenman, 2005) and also helped reduce "memory failures and distortions" (p. 83).

During the on-site classroom observations, sometimes I noticed "specific incidents or behaviors" (Merriam, 2016, p. 139). In this study, these incidents or behaviours were usually related to students' argumentation. Then, without much disturbance in students' work, I would initiate in-class informal interviews with them about these noticed incidents or behaviours. In other words, this kind of interview took place during the classroom observation and anchored to what was observed. It is noteworthy that the majority of the in-class informal interviews took place while students were working individually, such as searching online for the information they needed or developing their own arguments. This is because when students were working individually, without social interactions with others, there was a lower chance (compared with group work) for them to speak aloud their thinking processes and/or rationales behind their behaviours or arguments. In this case, to learn their inner thinking processes and rationales behind these observed behaviours or incidents, I would initiate in-class informal interviews, inviting students to share with me what they were thinking at that moment to gain access to students' Mc-A. For example, during the first focused activity (described in detail in the next chapter), when I noticed that student Zhao (pseudonym; all the students' and teachers' names in this document are pseudonyms) only explored NASA's information, such as NASA's websites and YouTube channel, and copied and pasted information from NASA's websites onto his information sheet, I initiated an in-class informal interview with him, asking, "This is NASA's website, right? Why are you particularly using the information from NASA?" (classroom recording transcript, 2018/04/04). I did this because these behaviours, such as what Zhao did, might indicate students' criteria for evaluating online information and interpreting information into evidence. Therefore, the in-class informal interviews with them helped the researcher learn students' McK-A (i.e., metacognitive knowledge specific to argumentation), such as what McK-A they had and how they applied it, etc. Another example is that when students were completing their argument evaluation task (described in detail in the next chapter) and trying to choose the argument they thought most convincing, I asked them questions such as "When did you make your choice, right after you read the question, or after you examined all these four statements, or anytime between?" and "Do you agree with the one you think most convincing?" (classroom recording transcript, 2018/05/04). With these questions during the in-class informal interviews, I learned students' thinking processes of evaluating various arguments, in addition to their written answers on the worksheets. Most of the in-class informal interviews were recorded with a voice recorder and transcribed later for further analysis.

Semistructured interview. Some students were also invited to participate in a semistructured interview at the end of the research period to learn their perceptions of their argumentative practices and the functions and roles of the teacher's scaffolds. (What these scaffolds looked like and how they were implemented are described in the next chapter.) These semistructured interviews were guided by a list of questions to be explored (see Appendix A). Neither the exact wording or the order of the questions was determined ahead of time. This interview format allowed me as the interviewer to respond to new ideas emerging during the interview. These semistructured interviews took place together with (right after) the second round of SRIs (see Figure 3.1). According to the research design, the main aim of this semistructured interview was *not* to access students' Mc-A; nevertheless, students sometimes talked about their thinking processes during the semistructured interviews as well. Therefore, there were also indicators of students' Mc-A discerned within these interviews. (How these indicators were discerned is discussed in "Data Analysis.")

Interview procedure. Collecting data through interviews involves, first of all, determining whom to interview. Students who were invited to the interviews were selected on the basis of "what they [could] contribute to the researcher's understanding of the phenomenon under study" (Merriam, 2016, p. 127), which, in this study, were their metacognition and scientific argumentation. Selecting the student interviewees in this way means engaging in purposive sampling. Specifically, I identified student interviewees mainly through the initial observation. The interviewees for the in-class informal interviews were based on my on-site observations, particularly the "specific incidents or behaviors" (Merriam, 2016, p. 139) I discerned during the classroom observation, which were usually related to argumentation. To discover the interviewees for the SRIs, I reviewed the video recordings of the classroom activities and identified episodes that included students' argumentative practices and/or possible indicators of their Mc-A. Students who were involved in these episodes then became the potential interviewees. Next, their willingness to share their thoughts with me and the teacher's suggestions were also taken into consideration. In this way, I selected students for interviews.

Table 3.2 *Information about the student interviews (interviewees and dates)*

	1st SRI	2nd SRI & the semistructured interview
Ivan	2018/05/04	--
Zhao	2018/05/04	2018/06/18
David	2018/05/04	2018/06/18
Nate	2018/05/04	2018/06/18
Levi	2018/05/09	--
Adam	2018/05/09	2018/06/18
Jayraj	2018/05/09	2018/06/18
Jaden	--	2018/06/18
Henry	--	2018/06/18

For the first round of SRIs, 8 students were invited. Henry was sick, thus could not make his first SRI. Therefore, 7 students participated in the first round of SRIs (see above in Table 3.2). For the second round of SRIs, Ivan (due to his family's plan for home visit) and Levi (for personal reasons) left school in the middle of the semester, thus could not make it to their second SRIs and semistructured interviews. Additionally, during the third focused activity, some episodes of importance (i.e., episodes including students' argumentative practice) in which Jaden was involved, were discerned. Thus, Jaden was invited for the second round of SRIs. Seven students were interviewed during the second round of SRIs. All the students who participated in SRIs were invited for the final semistructured interviews. I interviewed all these students individually in their school library, which is next to their classroom and very familiar to them. Each interview was around 40 to 50 minutes long. All the interviews were videotaped.

Self-reflection as the interviewer. Although the ideal in qualitative research is to get inside the perspective of the participants and understand the phenomenon of interest from their perspective, not the researcher's (Merriam, 1998, 2016), any interpretation is filtered through the researcher's personal experience and knowledge. Therefore, just as being the observer affected what I observed, myself as the interviewer (e.g., how I interacted with and responded to the interviewees) also affected what students shared with me and how I interpreted the interview data. Moreover, as Patton (2015) suggests, even if "the purpose of interviewing . . . is to allow us to enter into the other person's perspective" (p. 426), as with observation, the level of the information revealed is also controlled by the interviewees. These were things I needed to acknowledge and be aware of during the entire research period.

Specific to the interviews aiming to access students' Mc-A, it is noteworthy that these interviews not only helped gather data on metacognition, but also influenced students' metacognition. According to Thomas (2013), interviewing students about their thinking and learning processes stimulates students' metacognitive reflections. For example, video episodes shown in the SRIs were instrumental in assisting students to self-reflect on their learning and learning processes (Anderson & Nashon, 2007). Therefore, the SRIs provided "a mechanism beyond simple memory recall and an additional experience which [was] itself a metacognitive activity that enable[d] the participants to reflect on their metacognition and learning processes" (Anderson et al., 2009, p. 188). As a researcher using these methods, I acknowledge that SRI and in-class informal interview were not neutral data collection methods. They could and did influence the students being interviewed and their metacognition in this study. (How SRI influenced students' metacognition is reported in the Findings chapter.)

Moreover, employing interviews to collect data on students' metacognition means that what the researcher learns is based on what students share within the self-report interviews. Therefore, researchers need to be aware that interviewees, such as the young students in my study, might not accurately recollect their thinking processes back then due to "memory failure and distortion" (Veenman, 2005, p. 83). Even if specific techniques (i.e., offering students video episodes or their written work to stimulate their recall, initiating interviews concurrently while they were engaged in the tasks) had been used to minimize memory failure and distortion, they cannot be avoided or eliminated completely, thus would exist to a certain extent within the data collected in this study.

As discussed previously, students' responses during the interviews might be affected by their own expectations and the perceived expectations of the interviewer. This is seen as another limitation of the self-report interview as a data collection method. Specific techniques were employed to try to mediate this limitation. For example, all the interview participants were reassured that there were no wrong answers to any interview question, and their perspectives and ideas were what the researcher valued and appreciated. Nevertheless, it might be impossible to completely eliminate the influence of either their own expectations or the perceived expectations of the interviewer on their responses.

Moreover, through reflecting on the process of interviewee sampling, I noticed and acknowledged bias in my purposive sampling. As I described previously, student interviewees were selected based on my observation of their performances in classroom argumentation.

Students who were involved in the discerned episodes that included their argumentative practices and/or possible indicators of their Mc-A were invited to the interviews. In this way, the student interviewees usually were the ones who were active classroom participants and had verbal interactions with their teacher and peers. This bias might result in quiet students being underrepresented in my research, which I see as a limitation of this study.

3.4.4 Collecting Students' Writings

In addition to the interview and observation, I also collected students' writings. Many studies in literature have supported that students' writings could be an informative data source to understand their argumentation, both the final products of argumentation (e.g., Chen et al., 2016; Chen et al., 2017; McNeill, 2011; Kuhn et al., 2013) and the process of argumentation (e.g., McNeill, 2011; Kuhn et al., 2013; Ryu & Sandoval, 2012). Students' writings collected in this study included their written argument evaluation tasks and other classroom writing samples.

Argument evaluation task. Students' written responses to the argument evaluation task were collected in this study to gather relevant data on how students evaluated various arguments produced by others, their understandings of argument and argumentation, as well as their Mc-A. Moreover, during the SRIs, students' written responses to the argument evaluation task were provided to them to stimulate them to recall their thinking processes while they were performing argument evaluation. The argument evaluation task is described in detail in the next chapter.

Other writing samples. Besides the argument evaluation task, other writing samples were also collected as supplementary data sources to better understand students' argumentative practices. These writing samples included the arguments they developed in the NASA technology design project (i.e., students' design documents including PowerPoint slides, written transcripts for their presentations, blueprints, etc.), self- and peer-assessment of the NASA technology design, parachute design planning documents, glider design planning documents, and self- and peer-assessment of the parachute design.

Thus far, this part has described how the data were collected with various methods. In what follows, I describe how the collected data were analyzed to answer the research questions.

3.5 Data Analysis

To answer the research questions in this study, qualitative data analysis approaches were employed to analyze the data collected from the aforementioned sources. In this section, I describe how the data were analyzed.

3.5.1 Preparing Multiple Data for Further Analysis

Classroom videotapes were reviewed immediately after collected from the classroom. Besides reviewing the data, I also developed metadata by writing a video log (see Appendix B), which included time-index, participant structure, task description, and the analytic notes that described episodes which were closely related to or included students' argumentation and inferences about indicators of students' Mc-A. Researcher's field notes, which I wrote up while I was observing, were also integrated into the analytic notes in this video log for further analysis. By reviewing the classroom recordings, I determined episodes of importance, such as episodes including students' argumentative practices and/or indicators of students' Mc-A, that could be shown to students in the SRIs. This information (i.e., which episode could be shown to which student) was also included in the analytic notes. What follows are some examples of my analytic notes. The first two pieces (which can be seen in Appendix B) are from May 25, 2018. On that day students were working on revising their parachute planning document.

- [clip #01: 00123.MTS] 02:50—03:33 Including teacher's scaffolds: M [modelling thinking] Q&P [questioning and prompting]; 08:00 — around 12:00 students mentioned how to achieve consensus: D [David mentioned]: "evidence" "discuss"; I [Ivan mentioned]: "evidence is important"; students expressed their understandings of how to solve problem or resolve difference through discussion.

- [clip #04: 00126.MTS] Students were holding different ideas; Argumentation emerged but did not further develop until the teacher joined in the group; *08:42–09:11 possible clip to show to Nadia*.
(Analytic notes from the video log, 2018/05/25)

The following one is from April 13, 2018. On that day students were presenting their NASA projects and having Q&A with peers.

- [clip #14: 00091.MTS] 00:00—06:42 Henry's presentation (continued); Q&A starting from 01:10; 01:10—02:40 Henry & Nate: consensus achieved through AD [argumentative dialogue], evidence and justification are clear, *argu* *SRI* [indicating this part included students' argumentative discourse and could be shown to Henry and Nate in their SRIs]; 02:47—03:22 Henry & Zhao: question and answer, no clear argumentation; 05:07, 06:28 T C [teacher's comments];
(Analytic notes from the video log, 2018/04/13)

Classroom recordings of the focused activities and episodes of importance from the linking lessons, as well as the interviews and in-class conversations with students, were transcribed. I did all the transcription by myself. According to my analytic notes and descriptions of the video clips, some episodes were transcribed roughly; some (i.e., the ones I indicated as inducing important information, such as 02:50—03:33 and 08:00—12:00 in the clip#01 of 2018/05/25 and 01:10—02:40 in the clip #14 of 2018/04/13 [see above in the examples of my analytic note]) were transcribed word by word. When I did the transcription, especially of the video recordings, students' gestures (e.g., nodding, shaking heads, frowning, pointing to something) and changes in the tone of their voices were also recorded. This is because "argumentation may unfold in part in the form of signs other than words" and these other signs include such things as students' gestures (Kim & Roth, 2019, p. 25). Thus, students' unspoken language, gestures, or body movements helped me understand and interpret their activities.

As in many studies on students' argumentative discourse (e.g., Iordanou & Constantinou, 2015; Kim & Pegg, 2019; McNeill, 2011; Osborne et al., 2004; Sampson et al., 2011), transcripts of students' classroom argumentative discourse were analyzed using *dialogical turns* as the basic unit of analysis. Even if there was no compulsory turn-taking in students' classroom conversations or discussions, students usually take turns to express themselves. Thus, according to Grossen (2010), a dialogical turn could be the basic unit of analysis of students' argumentative conversation. Accordingly, students' argumentative discourse in these transcripts was broken into dialogical turns before analysis and for further analysis. In this process, students' body language, such as nodding, shaking heads, and frowning, as a part of their dialogue was also treated as a dialogical turn (e.g., turn #04 in the following example). What follows is an example (i.e., 01:10—02:40 in the clip #14 of 2018/04/13 [see above in the example of my analytic note]) showing how the transcript was divided and organized using dialogical turns (turn for short):

[turn #01] Nate: What kind of fuel or energy are you going to use to send off your space centre into space?
[turn #02] Henry: I will use gases, just like the gas cars use.
[turn #03] Nate: You know that gas is not the most efficient fuel, you will need a lot of gas, and it will generate lots of carbon dioxide.
[turn #04] Henry: [nodding along to Nate's words (the "carbon dioxide" part)]
[turn #05] Nate: I use antimatter as the power for my rocket. That is more efficient and cleaner than gas.
[turn #06] Henry: Yes, I think I will consider about it.
(Classroom recording transcript, 2018/04/13; also shown in example #08 in Chapter 5)

The initial plan of analyzing other transcripts (e.g., interview transcripts and transcripts of the teacher-led whole-class discussions) was to break them into sentences and then assign codes to these separate sentences. However, during the actual analysis, I realized that it was hard to break data such as the interview transcripts into separate sentences. When students shared their thoughts during the interviews, they sometimes did not use complete sentences. Sometimes, they used several complete or incomplete sentences or even single words to express a single idea. For example, when the aforementioned episode was shown to Nate during the SRI with him, he shared with me what he was thinking at the moment of asking Henry that question. He said:

> Nate: I was thinking, okay, this is going to happen, then, but, how, I was thinking the how, how exactly is this going to happen? I was thinking he might forget to put certain information to explain . . .
> (Interview transcript, 2018/05/04; also shown in example #08 in Chapter 5)

This, as an example, showed that it was difficult and not necessary to divide students' words into separate complete sentences. As shown in this example, all these sentences and words together as *a group of sentences/words* showed that Nate knew what he was thinking at that moment. With these sentences and words, it indicated that Nate knew the necessity and importance of evidence, thus, this group of sentences/words was interpreted as an indicator of Nate's declarative McK-A; At the same time, it also indicated that Nate was monitoring his own comprehension of Henry's presentation and realized that he was not convinced, thus this group of sentences/words, as a whole, was also interpreted as an indicator of Nate's metacognitive monitoring.

In this way, these transcripts (e.g., interview transcripts and transcripts of the teacher-led whole-class discussions) were broken into *groups of sentences/words* (including many sentences or part of a sentence or some single words) which were expressing the same idea or serving the same purpose, instead of single sentence. Similarly, students' writings and the researcher's field notes were also broken into *groups of sentences/words* for later analysis. (In the transcripts presented in the next subsection, I use *line* to refer to the *group of sentences/words* for short.)

3.5.2 Organizing Multiple Data into Clusters and Sub-Clusters for Further Analysis

Multiple data were then organized into clusters and sub-clusters. First, data related to students, except final semistructured interviews, were decided into four main clusters. The first focused activity (i.e., NASA technology design project) was divided into two clusters: cluster #01 focusing on argument construction and cluster #02 focusing on students' argumentative dialogues that took place during this project. Data collected during the second focused activity (i.e., argument evaluation task) were grouped into cluster #03 focusing on argument evaluation.

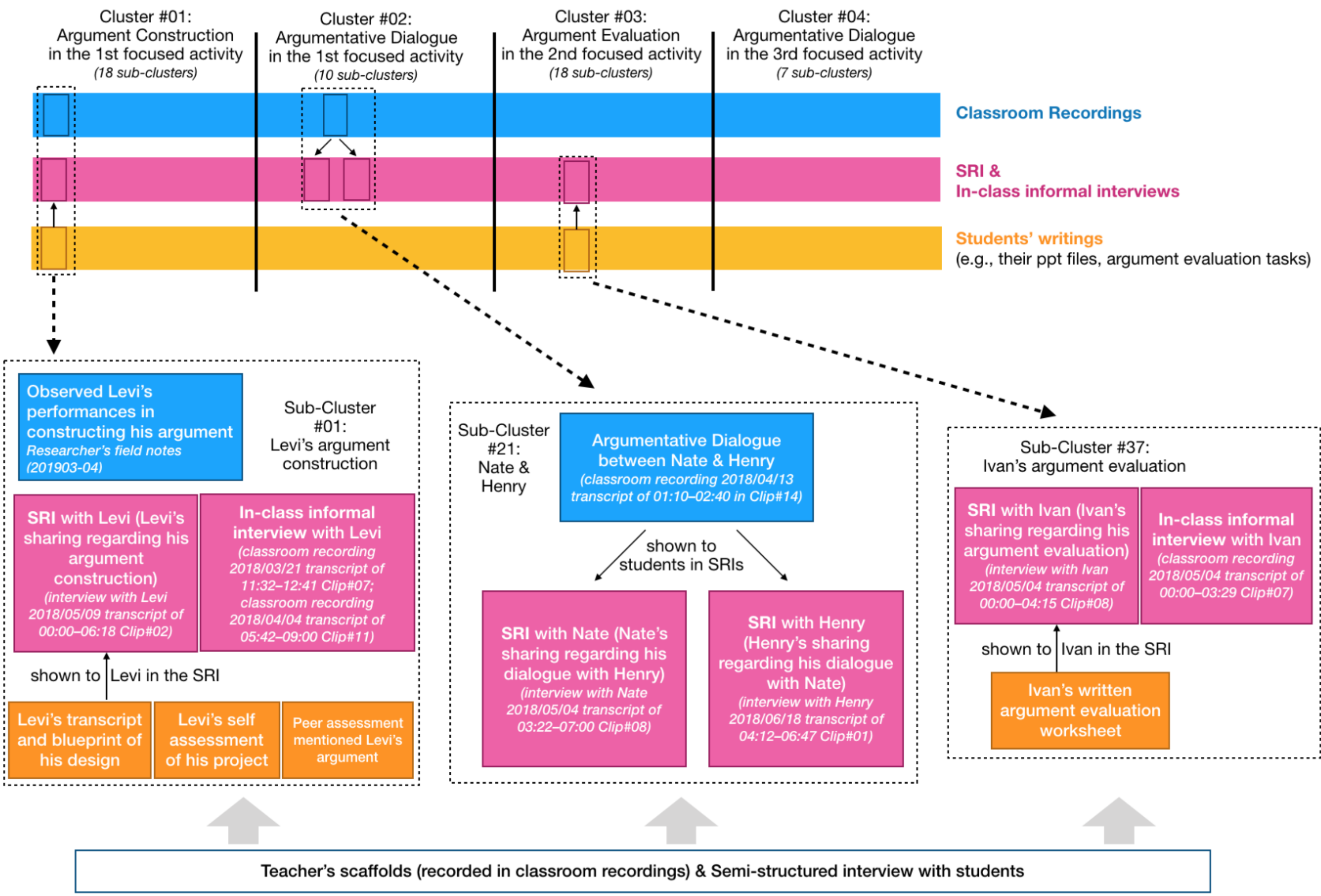


Figure 3.2 Overview of the process of organizing data into clusters and sub-clusters

Data collected during the third focused activity (i.e., parachute and glider model design, testing, and improving) were grouped into cluster #04 focusing on students' argumentative dialogues in a group problem-solving context. (These focused activities are described in detail in the next chapter.) As shown above in Figure 3.2, each cluster included relevant data: classroom recordings, SRIs and in-class informal interviews, and students' writings.

Then, as shown above in Figure 3.2, within each main cluster, data were further divided into sub-clusters. Both cluster #01 and #03 (i.e., data on students' individual argument construction and argument evaluation) were further divided into 18 sub-clusters with each one focusing on one student's argument construction/evaluation. Take sub-cluster #01, for example; this set of data was about Levi's argument construction. As shown above in Figure 3.2, the following data were included in this sub-cluster:

- the argument Levi developed
- the researcher's field notes about Levi's argument construction
- an episode of the SRI with Levi in which he reported his thinking processes of constructing his argument
- in-class informal interviews with Levi while he was constructing his argument
- his self-assessment of his own argument construction
- other students' peer-assessments in which Levi's argument was mentioned

All these data were analyzed together to interpret how Levi constructed his argument and how his Mc-A was involved in the process (see example #04 in Chapter 5). Some sub-clusters, like sub-cluster #01 shown above, included multiple data, while others (e.g., sub-clusters of data on students who did not participate in interviews) included less data. Clusters #02 and #04, which focused on students' argumentative dialogues, were also divided into many sub-clusters. The classroom recording episodes, which were discerned as episodes of importance and included students' argumentative dialogues and/or indicators of their Mc-A, were shown to relevant students (i.e., students who were involved in that dialogue) All these data were analyzed together to interpret the argumentative dialogue between Nate and Henry, as well as how their Mc-A was involved in the process. This sub-cluster is presented in the Findings chapter (Chapter 5) as example #07. In this way, the collected data were grouped into 53 sub-clusters in total. Data related to the teacher's scaffolds and students' semistructured interviews were not divided. They were used as a reference to interpret all these sub-clusters.

3.5.3 Analyzing Classroom Recording Transcripts

After the data were organized into sub-clusters, multiple data in each sub-cluster were analyzed together to understand students' argumentative practices. Classroom recording transcripts and the transcripts of SRIs and in-class informal interviews were the main data sources. In this section, I mainly describe how these data were analyzed.

Analysis of students' argumentative discourse. I developed an initial coding scheme for students' argumentative discourse by synthesizing relevant literature (e.g., Clark & Sampson, 2008; Chen, 2011; Kim, 2016). During the actual analyses of this study, that scheme was revised to include "challenging the relevance of evidence." During the data analysis, it was found that students questioned their peers regarding whether and how they could make sure the information they used as evidence was relevant to the topic. These questions were important for student argumentation, yet could not be covered by the existing categories or sub-categories in the initial coding scheme. Therefore, new sub-categories were developed and added to the coding scheme. "Challenging the process of experiment" and "challenging through comparing," which were sub-categories in the initial coding scheme, were deleted because no data related to these codes were discerned. These codes (i.e., sub-categories in the coding scheme) were assigned to the dialogical turns. Table 3.3 shows the finalized coding scheme, including descriptions and examples from the classroom data.

Table 3.3 *Coding scheme for students' argumentative discourse*

Category	Sub-category	Description	Examples
Question emerged	--	A question/problem is emergent	-- I want to know how my robots on other planets can communicate with the Earth? (*Nate; classroom recording transcript, 2018/04/09*)
Claim / Counterclaim making	--	Any claim an individual proposes to the question	-- … it [using X-ray or radio waves] will take a long time. (*Nate; classroom recording transcript, 2018/04/09*)
Supporting	Simple supporting	Any response used by an individual to accept or agree with someone else's ideas without further elaboration	--Yes, it [using X-ray or radio waves] will take decades to get there. (*David; classroom recording transcript, 2018/04/09*)
	Evidence-based supporting	Any response used by an individual to accept or agree with someone else's ideas supported by evidence	-- Yes, it does for me. I had exactly the same [experience]. (*Jayraj; classroom recording transcript, 2018/04/09*)
Defending	Simple defending	Any response used by an individual to persuade others about their ideas without further elaboration	-- … it should be 10, we need 10. (*Ivan; classroom recording transcript, 2018/05/30*)
	Evidence-based defending	Any response used by an individual to persuade others about their ideas supported with evidence	-- … I can get a lot. If you go to the Titan, the moon of Saturn, there were a lot of seas, like the liquid methane. So, I will go from the Earth, and stop by Titan to add more methane. (*Ivan; classroom recording transcript, 2018/04/13*)

Rejecting	Simple rejecting	Any response used by an individual to disagree with all or part of the speaker's ideas without further elaboration	--No, it does not. (*David; classroom recording transcript, 2018/04/09*)
	Evidence-based rejecting	Any response used by an individual to disagree with all or part of the speaker's ideas supported with evidence	-- That [sending and receiving emails in seconds] is because there are satellites to receive and transfer your information, but there is no satellite in space. (*Nate; classroom recording transcript, 2018/04/09*)
Challenging	Simply challenging	Any response used by an individual to question or critique other's ideas or arguments	--Really? (*Jayraj; classroom recording transcript, 2018/04/09*)
	Challenging the validity of evidence	Challenging/questioning that is focused on whether evidence or information is reliable or not	--Where are those specifically? How can you make sure that it is real? (*Nate; classroom recording transcript, 2018/04/13*)
	Challenging the relevance of evidence	Challenging/questioning that is focused on the claim-evidence relationship	-- … You should talk more about your topic. That is not related. (*Nate; classroom recording transcript, 2018/04/13*)
Consensus achieved	--	After negotiation, students reach an agreement	--Yes, I think I will consider about it. (*Henry; classroom recording transcript, 2018/04/13*) *This code was usually used to summarize results of the argumentation.*
No consensus achieved	--	After negotiation, students are still holding different ideas	*No dialogical turn was coded as "no consensus achieved"; this code was used to summarize results of the argumentation.*

Analysis of teachers' argument-focused metacognitive scaffolds. The teacher's scaffolds were also embodied in the classroom recording transcripts, so these recordings were also analyzed to identify Ms. Bowen's scaffolds. These scaffolds were distinguished and grouped into two categories: argument-focused metacognitive scaffolds and other scaffolds. The argument-focused metacognitive scaffolds were further distinguished as (1) questioning and prompting students' thinking during argumentation (*questioning & prompting* for short), and (2) teacher modelling thinking process related to argumentation (*modelling thinking* for short). Descriptions and examples of each are shown in Table 3.4, which is the coding scheme for the teacher's scaffolds in this study.

Table 3.4 *Coding scheme for teacher's scaffolds*

Category	Sub-category	Description	Example
Argument-focused metacognitive scaffolds	*Questioning & Prompting:* Questioning and prompting students' thinking during argumentation	Teacher uses questions or cues to further students' thinking about their own thinking or prompt their evidence-based thinking in argumentative practice	--…What do you think is your purpose? And what is your way of thinking to achieve this purpose? Just imagine how would the innovative technologists think in this situation? (*classroom recording transcript, 2018/03/14; focusing on the goal of argumentation: "to persuade"*) --… We are trying to make our arguments very strong, right? Then, what could be your thinking process of preparing the pitch, making your argument very strong? … (*classroom recording transcript, 2018/03/21; focusing on the importance of evidence*)
	Modelling Thinking: Teacher modelling thinking related to argumentation	Teacher demonstrates how herself or scientists or technologists think in argumentative	--… if I am going to do a pitch, I would try to think how to be convincing and persuasive, because, in my mind, this is the biggest piece of the writing, of developing your argument (*classroom recording transcript, 2018/04/04; focusing on the goal of argumentation: "to persuade"*)

	practices	--… later, when you present your technology, I will think "Do I understand his words?" … I will pay more attention to the part [about] whether your evidence is supporting your claim. (*classroom recording transcript, 2018/04/13; focusing on metacognitive monitoring, monitoring one's own comprehension through asking oneself questions*)
Other scaffolds	Scaffolds including metacognitive scaffolds in general (not particularly about argument or for argumentation) or scaffolds on the cognitive level, etc.	--Why do you want to work on something that interests you? (*classroom recording transcript, 2018/03/16)* --Let us think, let's think cars. Are people … still design new cars? We already had cars. Do you think the new cars are innovations? (*classroom recording transcript, 2018/03/16)*

3.5.4 Analyzing Transcripts of the SRIs and In-Class Informal Interviews

Analyses of the transcripts of the SRIs and the in-class informal interviews aimed at seeking insights into students' Mc-A. Students' Mc-A (i.e., indicators of students' Mc-A) were identified based on the definitions or limitations of Mc-A in this study (see Chapter 2). Table 3.5 below shows the coding scheme of students' Mc-A. There was one thing noteworthy about analyzing relevant data to explore students' metacognition: Because metacognition is a mental activity, any interpretation or measurement of metacognition involves different degrees of inference on the part of the researcher (Thomas, 2012); this is the case for the data analysis in this study. Interpreting students' Mc-A during the data analysis, as well as developing the coding scheme and deciding ways of collecting relevant data in this study, all involved my inference.

Table 3.5 *Coding scheme for students' Mc-A*

Category	Sub-category	Description	Example
McK-A	Declarative McK-A	Students' conscious, reportable and applicable knowledge of ✓ their conceptions or beliefs of argumentation, components or products of argumentation, ✓ their personal abilities in argumentation	-- … I just see which has more evidence and explain more clearly, because evidence and how you explain are important for being convincing … [*indicator of declarative McK-A: knowing the necessity and importance of evidence and justification*] (Nate; SRI transcript, 2018/05/04)
	Procedural McK-A	Students' conscious, reportable and applicable knowledge of ✓ how to perform or engage in the process of argumentation ✓ argumentation norms	-- I know that I need to do the research to, like, I researched the materials, the power, I researched on every part … to find really good evidence … [*indicator of procedural McK-A: knowing how to find the "good evidence"*] (Ivan; SRI transcript, 2018/05/04)
	Conditional McK-A	Students' conscious, reportable and applicable knowledge of ✓ when and why to engage in argumentation, i.e., goals of argumentation ✓ the value and limitations of procedural knowledge regarding different contexts	-- … to be convincing, I thought about … [*indicator of conditional McK-A: knowing the goal of argument construction is "to persuade"*] (David; SRI transcript, 2018/05/04)
McR-A	Monitoring	Students' consciously ✓ monitor and keep track of their thinking ✓ continually assess their comprehension	-- His [Nate's] evidence is convincing, actually, furthered my thinking, you know, I just thought the communication on Earth, and it was totally different from the deep space … [*indicator of metacognitive monitoring: monitoring his comprehension, knowing he was convinced and his thinking was "furthered"*] (Levi; SRI transcript, 2018/05/04)

Control	Students' conscious adjustment or control of their thinking during argumentation.	-- first …[I] thought about my personal interest, then [I thought] how I can connect soccer with space … Ms. Bowen told us that is the way [of thinking] we can generate a both innovative and realistic technology, and I agree, like, I also think so. So, I tried. [*indicator of metacognitive control*: *Indicating that he (positively) responded to the teacher's scaffolds about how to think to generate their topics]* (Henry; SRI transcript, 2018/06/18)

Besides these aforementioned transcripts, which were the main data sources in this study, students' writings, the researcher's field notes, and the transcripts of the semistructured interviews were also analyzed to enrich understanding of student argumentation. As mentioned previously, during the semistructured interviews, students also talked about and reflected on their thinking processes during argumentation. When it happened, those parts of the transcripts were interpreted with the coding scheme of students' Mc-A. Likewise, when students' argumentative discourse was shown and identified in their writings, these writings were further analyzed with the coding scheme for students' argumentative discourse (shown above in Table 3.3).

Thus far, I have described how data in this study were collected and analyzed to answer the research questions. In the next sections, I describe how the trustworthiness of research findings was achieved and my ethical considerations.

3.6 Quality Consideration: Trustworthiness

Typically, conventional criteria for judging the rigour of inquiries include internal validity, external validity, reliability, and objectivity. Within the framework of positivism, those criteria are perfectly reasonable and appropriate. However, these traditional criteria are unworkable for qualitative studies within the constructivist paradigm (Guba & Lincoln, 1981, 1989), as Lincoln, Lynham, and Guba (2011) argue. They state:

> We do not believe that criteria for judging either "reality" or validity are absolutist (Bradley & Schaefer, 1998); rather they are derived from community consensus regarding what is "real": what is useful and what has meaning (especially meaning for action and further steps) within that community, as well as for that particular piece of research (Lather, 2007; Lather & Smithies, 1997). (p. 116)

Therefore, in qualitative research within the constructivist paradigm, trustworthiness has developed to judge the quality of inquiries. Guba and Lincoln (1989) propose a set of trustworthiness criteria, which they also call "parallel criteria . . . because they are intended to parallel the rigor criteria that have been used within the conventional paradigm for many years" (Guba & Lincoln, 1989, p. 233). These trustworthiness criteria include credibility (paralleling internal validity), transferability (paralleling external validity), dependability (paralleling reliability), and confirmability (paralleling objectivity; Guba & Lincoln, 1994). This section describes the trustworthiness of the study's findings by examining how those criteria were applied in this study.

3.6.1 Credibility

Credibility refers to the idea of "isomorphism between constructed realities of respondents and the reconstructions attributed to them" (Guba & Lincoln, 1989, p. 237). That is, according to Guba and Lincoln (1989), instead of focusing on a "real" reality "out there," the focus of credibility is on establishing a match between the constructed realities of the research subjects and the realities represented by the researcher and attributed to the subjects. In this study, credibility was achieved through prolonged engagement and persistent observation, triangulation, and peer debriefing, as described below.

Prolonged engagement and persistent observation. This research was designed as a four-month case study with "substantial involvement at the site of the inquiry, to overcome the effects of misinformation [and] distortion [,] . . . to build the trust necessary to uncover constructions, and to facilitate . . . understanding [of] the context's culture" (Guba & Lincoln, 1989, p. 237). During the research period, I observed students' science learning, specifically their argumentative practices, in a science classroom. Moreover, the interviews with students provided me, as researcher, additional opportunities for observation. According to Guba and Lincoln (1989), "the object of persistent observation is to add depth to the scope which prolonged engagement affords" (p. 237). Sufficient observation in this study enabled me "to identify characteristics and elements in the situation that [were] most relevant to the problem or issue being pursued and to focus on them in detail" (p. 237).

Triangulation. According to Creswell and Miller (2000), triangulation is "a validity procedure where researchers search for convergence among multiple and different sources of information to form themes or categories in a study" (p. 126). Cohen, Manion, and Morrison (2007) describe triangulation as a validation approach, arguing that it is suitable when "a complex phenomenon requires elucidation" (p. 143). The complex phenomenon in this case study was students' Mc-A. Creswell and Miller (2000) write that "a popular practice [of triangulation] is for qualitative inquirers to provide corroborating evidence collected through multiple methods . . . to locate major and minor themes" (p. 127). In this study, data were collected through multiple methods, including observation, interviews, and collecting students' writings. The multiple data sources helped make "the narrative account . . . valid" (Creswell &

Miller, 2000, p. 127) because I as researcher relied on "multiple forms of evidence rather than a single incident or data point in the study" (p. 127).

Peer debriefing. Peer debriefing was also undertaken to review the research process (Creswell & Miller, 2000) and provided useful challenges and insights (Johnson & Christensen, 2014). I discussed my actions and interpretations during the study and my conclusions at the end of the study with my supervisor and critical peers (e.g., other PhD candidates from my department), who were familiar with but disinterested in this study. They provided support, played devil's advocate, challenged my assumptions, and asked hard questions about my methods and interpretations (Creswell & Miller, 2000; Lincoln & Guba, 1985). All of these contributions helped to establish the credibility of this study.

3.6.2 Transferability

Transferability, according to Guba and Lincoln (1989), may be thought of as parallel to external validity or generalizability; they explain that it "is always relative and depends entirely on the degree to which salient conditions overlap or match" (p. 241). They also argue that "the burden of proof for claimed transferability is on the *receiver*" rather than the inquirer (p. 241, emphasis in original). In this study, transferability was achieved by what Guba and Lincoln refer to as "thick description" (p. 241). Through developing thick description, I provided an extensive and careful description of the classroom environment, that is, the context in which the elementary students' argumentative practices and metacognitive experience were taking place. Through providing thick description of the classroom environment, classroom activities including the teacher's scaffolds and students' actions and interactions with each other, as well as how these activities were interpreted, I facilitated what Guba and Lincoln refer to as "transferability judgments on the part of others who may wish to apply the study to their own situations (or situations in which they have an interest)" (p. 242). In other word, thick description in this study provided substantial reference information for those seeking transferability of the results of this research to other elementary science classrooms.

3.6.3 Dependability

Dependability, according to Guba and Lincoln (1989), is parallel to reliability in that it is concerned with the stability of the data over time and over conditions. In other words, dependability is an evaluation of the quality of the integrated process of data collection, data analysis, and results/conclusions generation. A dependable study needs to be consistent. In this study, I adopted the inquiry audit technique for establishing dependability. That is, I invited a critical peer (another PhD candidate at my department) who was not involved in the research process to examine both the process and products of the research study. The purpose of doing so was to evaluate whether or not the interpretations and conclusions were supported by the data. According to Guba and Lincoln, within the constructivist paradigm, "methodological changes and shifts in constructions are expected products of an emergent design dedicated to increasingly sophisticated constructions" (p. 242). Thus, to achieve such an inquiry audit or external audit, those methodological changes and shifts that took place during the research process "need to be both tracked and trackable" (p. 242). In this study, all the processes and method decisions were carefully documented. That is, I set up an audit trail for both dependability and confirmability, as discussed in the next section.

3.6.4 Confirmability

Confirmability, parallel to objectivity, is concerned with assuring that the research data, interpretation, and conclusions "are rooted in contexts and persons apart from the evaluator and are not simply figments of the evaluator's imagination" (Guba & Lincoln, 1989, p. 243). This means that data can be tracked to their sources and that the logic used to formulate the data interpretations is “available to be inspected and confirmed by outsider reviewers” (p. 243). The aforementioned triangulation (of analysis methods and data sources) was one of the techniques for establishing confirmability. Besides triangulation, the audit trail also enabled the assertions made in this study to be traced back to raw data.

3.7 Ethics

Ethical concerns while doing qualitative research should be addressed adequately to maintain the quality of the conclusions drawn from the various data sources. In this section, I discuss the ethics for this study, including informed consent and assent, the researcher-participant relationship, and confidentiality and ethical treatment of the data.

3.7.1 Informed Consent and Assent

Informed consent insists that research participants have the right to be informed about the consequences and nature of the research they agree to participate in. The research participants must voluntarily agree to participate in the research without any form of coercion, and must be given all the information they require about the research in which they will participate. In addition, the subjects must be ensured that their privacy and confidentiality will be protected during the research, and that the data will be accurate and not fraudulent in any way. With respect to this study, I adhered to these informed consent criteria by carefully informing the research participants about the content of the research and their participation in it through letters of informed consent and assent.

Informed consent and assent for this study were obtained from the following groups: consent from the principal of the elementary school where the teacher and student subjects were from; consent from the elementary science teacher; consent from the parents of the students; and assent from the students. Each of the informed consent and assent letters (see Appendix F) indicated clearly that participation was entirely voluntary and that the participants could withdraw their participation at any time. The teacher letter clearly indicated that there would be no adverse repercussions to her employment or assessment if she chose to withdraw. The letters to students and their parents emphasized that their participation would not have any effect on students' course assessment.

Moreover, letters of assent and consent also included statements indicating the various data collection methods to be used in the study. The teacher and student participants were assured in the letters that their audio and video recordings and writings would only be used to gain information about metacognition, argumentation, and science learning and that no one but the researcher would view them. In addition, assurance was made that the data will be destroyed five years after the study has been concluded.

3.7.2 Researcher-Participant Relationship

The researcher-participant relationship is another ethical issue that the researcher should take into account during the data collection process. It is essential that the participants do not feel threatened by any differences between the researcher and the participants, especially the student participants, at any point in the study. To ensure that the researcher-participant relationship was not affected by any power relations, student participants were reassured that although their teacher was part of the study, they should not feel compelled to participate and their course assessment would not be contingent on their participation. With this reassurance, 18 students (out of 19 in total in the class) agreed to participate in this study. The teacher was also reassured that even if the school administrator agreed to allow the research to progress, she should not feel compelled to participate, and could withdraw at any time.

3.7.3 Confidentiality and Ethical Treatment of Data

The data collected from the teacher and the students were treated ethically by ensuring its anonymity. The interview data and other data, such as researcher's notes, in which participants' names were involved, were kept confidential by using pseudonyms. All the data have been kept in a secure area during the course of the research. Signed consent and assent forms and hardcopy data have been stored in a locked file in the researcher's home, to which only the researcher has access. Audio and video-recorded interviews and classroom activities, as well as the transcriptions saved on a computer hard drive, were kept secure and confidential with an encrypted password. In the final write-up (i.e., my doctoral dissertation) and any kinds of dissemination of my research findings (e.g., conference presentations), the anonymity of the participants is preserved by using pseudonyms and careful descriptions. Finally, assurances will be made that the data will not be held indefinitely but will be destroyed after a prescribed period of time (five years, as required by the research office of the University of Alberta). Once the study has concluded and the research data have been analyzed, a copy of the results will be made available to all of the participants.

3.8 Summary

This chapter, starting with my reflection on my own ontological and epistemological beliefs, has described the rationale for the use of qualitative case study, the setting and participants of this study, how the data were collected and analyzed, and the study's trustworthiness and ethics. Next, in Chapter 4, I describe the curriculum context, including how the scaffolds and focused activities were designed and implemented in this study.

CHAPTER 4

CURRICULUM CONTEXT

4.1 Science Curriculum

Data in this study were collected from three learning units in Ms. Bowen's grade 5/6 science class over four months from February to June 2018. These three units were (1) sky science, (2) air and aerodynamics, and (3) flight (Alberta Education, 1996). The first learning unit started before the data collection of this study. The second and third units were combined during the actual teaching and learning. There were two or three science classes per week. Usually, students had their science classes on each Monday and Friday and every other Wednesday. Classes on Monday and Wednesday were 70 minutes long, from 12:30 to 13:40; classes on Friday were 100 minutes long, starting at 12:30 and ending at 14:10. Sometimes, the schedule changed due to the school's and school district's events (e.g., there was no class on Friday, March 02, 2018, due to a teachers' convention). I observed all the science classes from February 23 to June 11. Table 4.1 below shows the topics of each unit and the students' science activities in this classroom during the data collection period.

Throughout the period of data collection, there were three argument-focused activities with various argumentation-related focuses, including argument construction, argument evaluation, and argumentative dialogue (see Table 4.1 below). These activities were a NASA technology design project (argument construction & argumentative dialogue); evaluating arguments about the air's weight/mass (argument evaluation); and a parachute and glider design, testing, and improving activity (argumentative dialogue in a group problem-solving context). Argument-focused metacognitive scaffolds, which aimed to engage students in argumentative practices and stimulate their metacognitive experiences, as well as other scaffolds from the

Table 4.1 *Overview of the science learning topics during the research period*

	Date	**Learning topics** (Sky Science)	**Classroom Activity**	**Focus**
Linking Lessons (3 weeks)	02/23	▪ Phases of the moon	1. Whole-class discussion 2. Students working in small groups and/or individually 3. Whole-class (wrap-up) discussion	
	02/26			
	03/05	▪ Constellations		
	03/07	▪ Planets and their moons		
	03/09			
1st focused activity: NASA Tech Design Project (5 weeks)	03/14	▪ Project introduction & learning the persuasive goal of this project ▪ Co-constructing the criteria of the project	1. Whole-class discussion 2. Students working in small groups 3. Whole-class (wrap-up) discussion	Argument Construction (Design project)
	03/16	▪ Co-constructing the criteria of this project (cont.) ▪ Framing claims (i.e., generating the specific topics/technologies of the project)	1. Whole-class discussion 2. Students working individually 3. Whole-class (wrap-up) discussion	
	03/19	▪ Revising claims (within the wrap-up discussion on 03/21, they started to talk about *evidence*)	1. Whole-class discussion 2. Some students getting feedback from the teacher and each other in small groups & other students working individually 3. Whole-class (wrap-up) discussion	
	03/21			
	04/04	▪ Justifying claims with evidence and reasoning (i.e., developing arguments)		
	04/06			
	04/09			
	04/12			
	04/13	▪ Final presentations ▪ Q & A following each presentation	1. Whole-class discussion 2. Students presenting their arguments followed by Q&A	Argumentative Dialogue (Design project)

	Date	**Learning topics** (Air & Aerodynamic and Flight)	**Classroom Activity**	**Focus**
Linking Lessons (2.5 weeks)	04/16	▪ Properties of air	1. Whole-class discussion 2. Students working in small groups and/or individually 3. Whole-class (wrap-up) discussion	
	04/20	▪ Air pressure and composition of air		
	04/25	▪ Bernoulli's principle		
	04/27			
	05/02	▪ How flying animals and aircraft fly		
2nd focused activity: Evaluating arguments (0.5 weeks)	05/04	▪ Completing the argument evaluation task: Evaluating arguments about the air's weight/mass	1. Whole-class discussion (brief) 2. Students working individually on the argument evaluation task	Argument Evaluation (Application of science concepts)
Linking Lessons (2 weeks)	05/07	▪ How flying animals and aircraft fly (cont.)	1. Whole-class discussion 2. Students working in small groups and/or individually 3. Whole-class (wrap-up) discussion	
	05/09	▪ Different designs of aircrafts		
	05/11			
3rd focused activity: Parachute & Glider design, testing and improving (4 weeks)	05/25	▪ Completing the parachute design planning document	1. Whole-class discussion 2. Students working in small groups 3. Whole-class (wrap-up) discussion	Argumenta-tive Dialogue (Group problem-solving task)
	05/28	▪ Building and testing the parachute model		
	05/30	▪ Revising the parachute design planning document		
	06/01	▪ Improving and testing the parachute model		
	06/04			
	06/08	▪ Completing the glider design planning document	1. Whole-class discussion 2. Students working individually 3. Whole-class (wrap-up) discussion	
	06/11	▪ Building, testing, and improving the glider		

teacher, were integrated into the classroom teaching throughout the entire period of data collection, particularly during the three focused activities. In other lessons, which are referred to as linking lessons in this study, Ms. Bowen also used these scaffolds whenever she thought appropriate.

Usually, at least during the focused activities, Ms. Bowen would organize students together at the beginning of each class to introduce the learning activities, share with students the purpose of certain 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. Table 4.1 (see above) shows the overview of the three learning units in Ms. Bowen's classroom.

4.2 Focused Activities and Scaffolds

4.2.1 Collaborative Design for the Argument-focused Metacognitive Scaffolds

Before the data collection started, I had two informal meetings with Ms. Bowen (2018/02/12 & 02/16) to discuss the scaffolds and focused activities. The first meeting focused on what kinds of scaffolds Ms. Bowen felt comfortable to employ in her classroom teaching. During that meeting, we discussed several scaffolds that were reported in the literature and had been adopted by teachers or researchers to try to stimulate students' metacognitive experiences. These scaffolds included the use of prompts, cues, and questions; group discussions of thinking and learning; reflective writing; and teacher modelling (e.g., Conner, 2007; Davidowitz & Rollnick, 2003; Georghiades, 2004, 2006; Kipnis & Hofstein, 2008; Peters & Kitsantas, 2010; Shamir et al., 2008; Yilmaz, Cakiroglu, Ertepinar, & Erduran, 2017). Ms. Bowen shared with me that she felt more comfortable with teacher modelling and using prompts, cues, and questions. She explained, “They [these two kinds of scaffolds] fit with my way of teaching. . . . I love using questions to further their [students’] thinking. . . . I also share with them [her students] how I think” (conversation with the teacher, 2018/02/12).

In our second meeting, I brought Ms. Bowen the materials I had developed (see Appendix C) about argument-focused metacognitive scaffolds, particularly *teacher modelling thinking processes related to argumentation* (*modelling thinking* for short) and *questioning and prompting students’ thinking during argumentation* (*questioning & prompting* for short). That four-page-long material included some examples both from the literature (i.e., Yilmaz et al., 2017) and designed by myself. In Yilmaz et al. (2017), which is a study focusing on argumentation-based science teaching, teachers modelled how students would think while they were constructing an argument and reminded students to focus on how they think by asking them certain questions (shown in Appendix C). Yilmaz et al. (2017) described some episodes of classroom conversations including the use of these scaffolds. I included two such episodes as examples in the materials provided to Ms. Bowen. Besides the examples from Yilmaz et al. (2017), I also framed some examples based on my understanding of argument-focused metacognitive scaffolds. It was emphasized in the material that they were only *examples* for the teacher to use for reference. During the conversations with Ms. Bowen, I assured her that she could use any types of scaffolds whenever she thought appropriate and was not limited to the two we had discussed. In this way, Ms. Bowen and I designed the scaffolds collaboratively. All these scaffolds were implemented by Ms. Bowen. How the scaffolds were implemented and what they looked like in the science classroom teaching are described in the episodes in the next section.

4.2.2 Focused Activities and the Implementation of Scaffolds

In our second meeting, we also discussed possible focused activities that could be included in Ms. Bowen's classroom science teaching. Taking the research purpose, the school schedule, and curriculum contents, etc., into consideration, three activities focusing on student scientific argumentation were designed and implemented (see above in Table 4.1). In what follows, I describe how these three activities were implemented and how the teacher's scaffolds, particularly the argument-focused metacognitive scaffolds, were embedded in these activities, with illustrating episodes from the classroom activities (see Appendix D for full transcripts of these episodes and the researcher's analysis notes). Most of these episodes were from the teacher-led whole-class discussions, in which the teacher embedded her scaffolds. Because the first focused activity, the NASA design project, had two parts, which focused on students' argument construction and argumentative dialogue respectively, these two parts are described separately in what follows.

The first part of the NASA technology design project and scaffolds within it. The first focused activity was the NASA technology design project, which lasted for about five weeks. This project included two parts, focusing on argument construction and argumentative dialogue respectively. At the end of the first unit on sky science, students were encouraged to design a technology for future space exploration. To better engage students in this activity, Ms. Bowen built a scenario. In this scenario, all the students were innovative technologists in NASA, and they were aiming to design a technology to further NASA's current space exploration. At the beginning of this project, students were told that they would have a presentation to pitch 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 and related to what they knew and had learned in this unit. Moreover, they were encouraged and required to use various evidence, either from their science classroom learning or their online research, to demonstrate that their technology was reasonable and useful. In this way, they were engaged in argument construction. During this process of argument construction, there were some teacher-led whole-class discussions through which Ms. Bowen provided students supports and scaffolds, including the argument-focused metacognitive scaffolds. In what follows, I describe three episodes of the teacher-led whole-class conversations that took place during the argument construction part of the first focused activity, to illustrate what the argument-focused metacognitive scaffolds looked like and how they were implemented by the teacher. These three episodes focused on (1) the goal of argumentation (i.e., the goal is "to persuade"), (2) how to frame claims, and (3) the significance of evidence, which was critical to students' scientific argumentation and also important for students' learning in this focused activity and subsequent ones.

Scaffolds focusing on the goal of argument construction: "to persuade." The first episode (see Appendix D-1 for a full transcript and the researcher's analysis notes) was from the first lesson (2018/03/14) in this NASA technology design project. In this lesson, through the teacher-led whole-class discussion in which the argument-focused metacognitive scaffolds were embedded, the teacher built the scenario and introduced students to the project (i.e., students were supposed to design their own innovative technologies, that is, to construct their own arguments individually) and its goal (i.e., the main goal of the argument construction was "to persuade"). At the beginning of this class, Ms. Bowen built a scenario in which all the students were innovative technologists in NASA. Before directly leading students to do this project, Ms. Bowen used a video to engage the students and, using her words, "to inspire [students'] thoughts and to give [students] a good understanding of why the work [they were] doing [was] very important" (Line #07 in Appendix D-1). Then, Ms. Bowen provided argument-focused metacognitive scaffolds, particularly *questioning & prompting* (Line #11, #13, and #16). Through questioning how the technologists would *think* when they wanted to introduce their most important ideas to NASA, Ms. Bowen engaged students in an explicit discussion of their thinking processes. Being asked questions such as "As the NASA innovative technologists, if you want to introduce your most important development or your opinion . . . what do you think is your purpose?", "What is your way of thinking to achieve this purpose?" and "Just imagine how would the innovative technologists think in this situation?" (Line #11 & #13) and how they could think to develop this project (Line #13), students responded and realized that they needed to *prove* and to *persuade* other people that their ideas were good. Levi mentioned that they needed to "prove" and "persuade other people" that their design could be a good idea (Line #12 & #14). David, building on Levi's idea, said that "yes, like, think how to be persuasive, think how to prove and persuade NASA that mine is unique and they should support it" (Line #15). During their discussion, Ms. Bowen also shared with her students that "you might have different things you want to pursue, but the way of thinking to develop the project is quite similar here" (Line #13). Then, after students realized and explicitly discussed the goal of argument construction (i.e., "to persuade"), Ms. Bowen further confirmed and reinforced it by saying "Absolutely! You're proving your idea, you are pitching it actually," followed by modelling how people would think in a parallel situation, such as a company:

> Ms. Bowen: If you are in a company and you have something to pitch, what will you do? How do you think to make the pitch? You probably think that you need to convince the management or whoever it is why your idea is great. So, your assignment then will be to represent this, so you're going to think about how you could represent this, and how you can convince us, your colleagues, other technologists in NASA, right? Now, you know

> that you need to be persuasive and to be convincing, right? [students agreed and said "yes"]
> (Classroom recording transcript, 2018/03/14; also shown in Appendix D-1 Line #16, #17)

So far, with all the scaffolds, students came to realize that the goal of their technology design (i.e., argument construction) was "to persuade." This goal was also emphasized in later classes (e.g., science classes on 2018/03/16 and 2018/03/21).

Scaffolds during framing and revising claims. After students accepted that the goal of this design project was "to persuade," they moved into the next stage: framing and revising their claims. In this project, students' claims shared the same format that was: 'NASA should approve and support my technology: _____________'. Therefore, framing and revising their claims in this project referred to generating and refining the topics of their projects (i.e., thinking about and deciding the technologies they wanted to design and pursue).

The episode I describe in this part (refer to Appendix D-2 for full transcript and the researcher's analysis notes) was from the second lesson in this NASA technology design project (2018/03/16). From this lesson/episode, students started to think about and further refine what technologies they wanted to design; that is, frame and revise their claims.

Regarding the teacher's argument-focused metacognitive scaffolds during this period (i.e., framing and revising claims), I provide my rationales for how I interpret these scaffolds before I further describe them. At the beginning of this class, with a carefully selected video from YouTube published by NASA, the teacher introduced criteria for the technologies that students were going to design. These criteria were: being "both innovative and realistic," and being able to expand human being's "knowledge about the space" (Line #02, #03 in Appendix D-2). In this way, the teacher connected developing an innovative idea to framing the claim. Therefore, in this specific context, teacher's scaffolds to support students to think creatively to develop their innovative ideas (for example generating innovative ideas through connecting personal ideas with existing knowledge; these scaffolds are described in the following) were seen, coded and described as argument-focused metacognitive scaffolds as well, as they are related to their claims and arguments.

After Ms. Bowen introduced these criteria, regarding how to be “both innovative and realistic,” students expressed their concerns, as ‘being innovative’ and ‘being realistic’ seemed like contradictory with each other to some students. Students, like Levi, understood ‘being innovative’ as “making up” some “imaginary technologies” (Line #04, #11). Noticed students’ confusions, the teacher employed *modelling thinking* and *questioning & prompting* to further explain and elaborate what being “both innovative and realistic” meant. For example, the teacher, first, asked students to think whether “the scientists and technologists in NASA just making up these technologies” and how they could make these innovations (Line #05). Then, based on student’s response that “[scientists] are educated” (Line #06), the teacher modelled how scientists would think while they were trying to be innovative saying that “they think innovative ideas based on their knowledge, what they have known.” After students accepted this (as students were nodding and agreeing with the teacher), the teacher asked students again “how could we do, how could we think” to make their technology design innovative and realistic (Line #07) and further proposed that “we use information from reliable sources to support our design … to make our design both innovative and also realistic” (Line #09). Yet, about the “reliable [information] sources” and the ‘innovative technologies’, students expressed their concerns again, as they thought there would not be information available about innovation as “innovation … is new” (Line #10). To further help students understand how to think innovatively and what ‘being innovative’ means, Ms. Bowen explicitly asked her students “does innovation need to be something completely new … something that no one has heard before?" (Line #12) and invited students to think why people "still design new car" (Line #12). With these scaffolds, the teacher explained to her students what innovation was (i.e., "innovation does not have to be something completely new," and it could be changing, improving, creating or inventing things). Moreover, through *modelling thinking,* she also showed her students how to think innovatively to generate their topics (i.e., frame their claims):

> Ms. Bowen: … try to think like that, first, think about what interests you, and then, think about how we can find what we have already known about it, what we talked about, what you have learned about. Then, based on your personal interest and the knowledge you know, you will have your topic, and you will also make your technology both innovative and realistic. Then, you explain how your technology is benefitting NASA and entire human being. In this way, your argument will be very strong.
> (Classroom recording transcript, 2018/03/16; also shown in Appendix D-2 Line #15)

Thus far, with all these scaffolds, the teacher introduced and explained how to think to generate their innovative and realistic topics, that is, how to frame their claims.

Then, the class moved to another part, using the teacher's words, "giving [students] some context of what has been happening in the present time in space technology development … to give [students] some inspiration" for thinking of their own technologies (Line #17). The teacher played a video showing NASA's to-do-list including possible directions that students could pursue. It is noteworthy that, with the teacher's previous scaffolds, some students were still confused to some extent with 'what innovation is', as the teacher noticed and said that "I heard you guys said while we were watching that we've done some of those things" (Line #19). Thus, the teacher took this opportunity to further facilitate students' understanding of 'being innovative'. Specifically, the teacher asked students "why would it still be on the to-do-list?" (Line #19) Based on students' answers such as "[to] expand what we have done" and "to improve it" (Line #20, #22, #24), the teacher further explained "what innovation is, [particularly] it does not have to be something completely new" (Line #25). After discussed and talked 'abstractly' about how to think of possible technologies, the teacher showed and worked together with her students on an example. The teacher invited students to think together for example "if I am interested in the Sun … what do you think I can explore" and what the possible technologies could be pursued (Line #26). Then, the teacher and students worked together thinking possible ideas around the Sun that they can pursue. After working on that example, the teacher further explained to her students what they were going to do and introduced the term 'claim' to the students:

> Ms. Bowen: … you will need to think a realistic and also very innovative technology, which you will need to persuade us that it should be approved and supported by NASA. That is your claim. So, basically, claim is your statement, your answer, your opinion about, like a question. In this situation, the question is 'whether NASA should approve and support your design?' Right? So, what could be your statement, your answer to this question? Your answer is your claim. So, 'your technology, your innovative design should be supported by NASA' is your claim.
> (Classroom recording transcript, 2018/03/16; also shown in Appendix D-2 Line #27)

While students were doing the planning, they were also encouraged and supposed to do some online research as "the researching is helping your planning" (Line #27). The teacher employed *modelling thinking* and explained to and showed her students how they could think and do while they were doing their online research to frame their claims, in the similar way with the scientists' way of thinking and doing:

> Ms. Bowen: … you have an idea, let us say that is your personal interest, you think how to connect that with the space, this is the innovative part, right? Then, you do your research, you find what people have already known about this topic, how can I improve it or make it better. Of course, you can think something new … As your research goes, you will have more and more information about your topic, then you might want to change your original one, that is totally fine, that is great actually, this is how scientists and technologists work, right?
> (Classroom recording transcript, 2018/03/16; also shown in Appendix D-2 Line #27)

After this, students were dismissed to work individually to generate their topics, that is, to frame their claims. This class was essential for students to frame their specific claims, which shared the same format: ‘NASA should approve and support my technology: _____________’. In this class, they discussed and achieved the consensus that their technologies needed to be ‘both innovative and realistic’ to be approved and supported by NASA. Moreover, students were also introduced and discussed that it could be a good and feasible way of thinking to generate their ‘both innovative and realistic’ technologies based on considering what interested them together with what they knew about the current space exploration related to their interests.

In the next two classes (on 2018/03/19 and 2018/03/21), students continued to work individually on framing and further revising their claims. Within the teacher-led whole-class discussions at the beginning and the end of these classes, the teacher continually implemented her scaffolds. For example, before she dismissed students to work individually, the teacher further reminded students and emphasized the way of thinking to generate and revise their claims through *questioning & prompting*, asking students that “why would you like to work something interesting to you? why would you like to first think what interest you when you are deciding your research topics?” Some students responded with “be more motivated,” “you are good at the thing you like” and “it will make the assignment very fun” etc. (classroom recording transcript, 2018/03/19). During these classes, while students were working individually, the teacher organized several students together as a small group, usually three or four students at a time. With the teacher’s questions, such as “What is your technology?”, “How did you come up with this idea?” and “What was your thinking process of generating this idea?”, students shared with their teacher and peers within the group what their claims were and how they came up with their claims. Then, their peers in the group were encouraged to provide them feedback and suggestions. Moreover, besides the *questioning & prompting*, during the group sharing and discussion, the teacher also modelled the thinking processes of how scientists and engineers generated topics they wanted to pursue (i.e., *modelling thinking*) to continually emphasize and remind students the way of thinking they had discussed. For example, when the teacher was working with Nate, Adam, Henry, and Maria, after Henry shared how he came up with his topic through connecting his personal interest with his "research on NASA's current and previous projects," the teacher confirmed and further emphasized this way of thinking with the following words:

> Ms. Bowen: . . . this is how scientists and engineers think and work, right? They asked themselves am I interested in this, am I wondering about this, and then, they would think what has human beings already known about this, so that they can further contribute, like, and how can I change this . . .
> (Classroom recording transcript, 2018/03/19)

After students got the feedback and suggestions from their teacher and peers, they continued to work individually to further revise and finalize their claims.

Through the learning in these lessons (i.e., classes on 03/14, 03/16, 03/19, 03/21 and focusing on the goal of argument construction, and on framing and revising claims), students agreed and appreciated the goal of this NASA technology design project (i.e., the goal of argument construction is "to persuade"), learned what being innovative meant and how to think to generate a technology that was both innovative and realistic for their projects, and completed framing their claims, which were also the specific technologies that they wanted to pursue and present to NASA. Then, the teacher led students into the next stage of their project: justifying their claims with evidence and reasoning.

Scaffolds focusing on evidence and reasoning within whole-class discussions. At the end of the class on 2018/03/21, the teacher led the whole class to have a summarizing wrap-up discussion, which is shown in Appendix D-3. Within this teacher-led wrap-up discussion, the goal of argument construction was further emphasized. Moreover, with the teacher's scaffolds, students started to consider how to be convincing and talk about the necessity and importance of evidence, which is critical to argumentation. In this episode, the teacher first confirmed with students the goal of their pitch by saying, "Yes, exactly, to persuade! The goal of the pitch is to persuade NASA to approve and support your technology" (Line #05 in Appendix D-3). Then, the teacher took this opportunity to remind students what a claim is and also introduced them to what an argument is:

> Ms. Bowen: The goal of the pitch is to persuade NASA to approve and support your technology. That is your claim, right? Like, smoothies for the astronauts, the rovers to explore outer space, whatever your technology is, "your technology should be approved and supported" is your claim. Doing a pitch is to support your claims and make your arguments very strong. The pitch, the entire pitch, we also call it "argument." It includes your claim and how and what you are going to use to support to prove your claim. The entire thing we call it an argument. . .
> (Classroom recording transcript, 2018/03/21; also shown in Appendix D-3 Line #05)

In this way, the teacher introduced students to these terms in the context of argumentation (i.e., while students were constructing their arguments), instead of being separated from engaging students in argumentative practice. Moreover, it is noteworthy that the teacher introduced what argument is by connecting argument, which was a new term to the students, with pitch, which was a word students were already familiar with, saying "the pitch, the entire pitch, we also call it argument." After she introduced these terms (i.e., claim and argument), in the following conversation, the teacher continuously used these terms to communicate with students and familiarize students with these terms. Specifically, the teacher asked, "We are trying to make our arguments very strong, right? Then, what could be your thinking process of preparing the pitch, making your argument very strong?" Being asked these questions, students consequently realized and responded that "supportive information" helped to be persuasive (Line #06). Then, through responding to students' words, the teacher introduced another term: evidence, by saying, "Information! For sure! Ultimately your pitch, your argument is going to convince the panel . . . with all the helpful information you have, which is your evidence" (Line #07). Next, the teacher continued to ask how the students could know or make sure that their argument was convincing (Line #07), which triggered students' discussion about and realization of the sufficiency of evidence (Line #08, #09). Levi mentioned that "more reasons is better than less" (Line #08). Then, based on students' words, the teacher gave an example of the "not so good" evidence to engage students in explicit discussion around what "good evidence" was.

> Ms. Bowen: Yeah, more reasons, like sufficient reasons, right? Sufficient evidence to prove your technology is good. It is important for sure! How about, let's take Kelvin's for example, my ideas [developing smoothies for astronauts] is great, because I love smoothies, persuading? What you think? [Students were all laughing]
> (Classroom recording transcript, 2018/03/21; also shown in Appendix D-3 Line #10)

With the teacher's example and questions, students started to talk about and share what they thought was "good evidence," such as the "research, something from experts and books," and knowledge from classroom learning (Line #13, #14). They also mentioned that good evidence needed to be reliable and "make sense to other people" (Line #15).

Ms. Bowen also encouraged students to monitor their thinking while they were preparing their own work and listening to others'. Ms. Bowen reminded and asked students to keep in mind such questions as "Does this make sense to me?" or "Will this make sense to other people?"

> Ms. Bowen: Make sense to other people, that is very important. You do not want to talk about something that no one can really understand, right? You want your audience to know it. This reminds me when we prepare ours or listen to others', try to think, like "will this make sense to other people?" "does this make sense to me?" Like David said, make sense to the audience, to the panel, to whoever you are presenting to is important.
> (Classroom recording transcript, 2018/03/21; also shown in Appendix D-3 Line #16)

Finally, Ms. Bowen ended the discussion by showing students her own thinking process of developing an argument with evidence:

> Ms. Bowen: . . . if I am doing my pitch, I will first think about a topic that really interests me and using sufficient and good evidence to prove and persuade other people that my technology is good to pursue. When I am doing it, I will also think questions like "Is my argument convincing?" "Do I have enough evidence?" "Is my evidence really good and from reliable sources?" and "Does it make sense to other people, my evidence and my explanation?" all the time. This is my way of thinking of preparing my pitch, developing my argument.
> (Classroom recording transcript, 2018/03/21; also shown in Appendix D-3 Line #17)

Through this teacher-led whole-class discussion (shown in Appendix D-3), with the scaffolds including both the *questioning & prompting* and *modelling thinking*, the teacher emphasized the persuasive goal of argument construction, introduced the terms related to argumentation (i.e., claim, argument, and evidence), and guided students to start thinking about the necessity and importance of evidence and supporting their claims with evidence. With all of these scaffolds, the teacher prepared students for the next stage: justifying their claims with evidence and reasoning (i.e., science classes on 2018/04/04, 04/06, 04/09, 04/12).

Within this *justifying* period, scaffolds were also provided during the teacher-led whole-class discussions at the beginning and end of each class. For example, at the beginning of the class on 2018/04/04, the teacher emphasized again the goal of argument construction by *modelling* to the whole class: "If I am going to do a pitch, I would try to think how to be convincing and persuasive, because in my mind, this is the biggest piece of the writing, of developing your argument" (classroom recording transcript, 2018/04/04). In addition, in these classes, with the teacher's scaffolds, such as asking "How do you think you can make your argument very strong?", the students further discussed the validity of evidence. For example, Zhao said, "you need to make sure the information you used is true." They also discussed how to present different evidence, such as when Nadia said "instead of [presenting] many many reasons, you really want to say the ones which are really really important first" (classroom recording transcript, 2018/04/04). Moreover, they also talked about different kinds of evidence. In other words, students realized that hypothetical evidence and inferring could also help justify their claims. For example, when Adam was invited by the teacher to share his thinking process of developing his argument (i.e., teacher's scaffold: *questioning & prompting*), he said, "I think I said why my technology is important, that is also, kind of, evidence to show NASA they should approve my design, because if they invest in my technology, it will bring lots of benefit" (classroom recording transcript, 2018/04/06). Within these classes (i.e., science classes on 2018/04/04, 04/06, 04/09, 04/12), students did their online research searching for evidence, organized and synthesized their evidence to support their claims, completed their writing (or drawing), and finally, got their presentations ready for sharing.

Scaffolds focusing on evidence and reasoning within small-group sharing. During this *justifying* period (i.e., science classes on 2018/04/04, 04/06, 04/09, 04/12), students worked individually most of the time to develop their own arguments. The teacher also organized a few students together to give them feedback and suggestions and encourage them to give each other the same. The teacher organized the group work, in her own words, "according to the progress of their projects" (conversation with the teacher, 2018/04/06). That is, the teacher would invite students who were at a similar stage in their projects (e.g., students who had finished the draft of their writing and were ready to revise) to share together and give each other feedback.

The episode I am describing (see Appendix D-4 for a full transcript and my analysis notes) is an exemplar illustrating what the small-group sharing and the teacher's scaffolds during the group work looked like. At the time of this episode, these four students (i.e., David, Nate, Levi, and Jayraj) all finished their drafts and wanted to revise and improve their work. This episode was the first part of their teacher-organized group sharing and included two students (i.e., David and Nate) sharing and getting feedback from their teacher and peers. When they were working on David's project, through asking students questions such as "You need to buy my technology, because it is very good. Is this persuading?" (Line #11) and "… do you think the 'so many functions' are really related, really relevant to the decision of buying it?" (Line #13), Ms. Bowen drew students' attention to the relevance of evidence and reasoning. Then, Ms. Bowen further modelled how to think from the audience's perspective and reminded and encouraged students to take their audience into consideration:

> Ms. Bowen: Remember, we have an audience, we try to think how they would think to make their decision, right? They will think, David's design is very good, and we also need his technology, then, we will definitely buy it, right? The "it is good" part is important, but provide more information about why they need it, what your technology can bring them, etc., that will make all your evidence more relevant to your claim … (Classroom recording transcript, 2018/04/09; also shown in Appendix D-4 Line #15)

When they moved to Nate's work, students themselves had much to share. Argumentation among them emerged and developed well (this will be further discussed later). Instead of intervening, the teacher let students discuss by themselves. In this case, giving students opportunities and space to explore by themselves is also a kind of facilitation of learning.

Similar scaffolds (i.e., *questioning & prompting* and *modelling thinking*) were also provided to other groups. For example, when the teacher was joining Henry, Jayraj, Maria, and Xander as a small group, to further help Xander develop his project, through *questioning & prompting,* the teacher asked him "What do you think is your purpose?" and "What is your way of thinking to achieve this purpose?" and encouraged him to "imagine how would the innovative technologists think in this situation" (Classroom recording transcript, 2018/04/06).

Thus far, as they worked on this NASA project for a few weeks, students learned the goal of argument construction, framed and revised their claims, and further justified their claims with evidence and reasoning. Table 4.2 below summarizes the teacher's scaffolds during this period, presenting examples, purposes, and types of these scaffolds.

Table 4.2 *Summary of the teacher's scaffolds for argument construction*

Stage of argument construction	**Purpose** (what the teacher wanted students to learn)	**Examples** from the teacher's scaffolds & **Types** of the scaffolds	
Project Introduction	The persuasive goal of argument construction	▪ "As the NASA innovative technologists, if you want to introduce your most important development or your opinion . . . what do you think is your purpose? And what is your way of thinking to achieve this purpose? Just imagine how would the innovative technologists think in this situation?" (Classroom recording transcript, 2018/03/14)	Q&P
		▪ "If you are in a company and you have something to pitch . . . you probably think that you need to convince the management or whoever it is why your idea is great." (Classroom recording transcript, 2018/03/14)	MT
		▪ "if I am going to do a pitch, I would try to think how to be convincing and persuasive, 'cause in my mind, this is the biggest piece of the writing, of developing your argument" (Classroom recording transcript, 2018/04/04)	MT
		▪ "You might have different things you want to pursue, but the way of thinking to develop the project is quite similar here." (Classroom recording transcript, 2018/03/14)	other
Framing & Revising Claims	Ways to think innovatively to generate ideas which are "both innovative and realistic"	▪ "Are these scientists or technologists in NASA just making up these technologies? How do you think they made these innovations?" (Classroom recording transcript, 2018/03/16)	other
		▪ "they [the scientists] think innovative ideas based on their knowledge, what they have known." (Classroom recording transcript, 2018/03/16)	MT
		▪ "you are not thinking to make up your technology, you are thinking to make something based on what you have already known" (Classroom recording transcript, 2018/03/16)	Q&P
		▪ "try to think like that, first, think about what interests you, and then, think about how we can find what we have already known about it, what we talked about, what you have learned about." (Classroom recording transcript, 2018/03/16)	MT

		▪ “this is how scientists and engineers think and work, right? They ask themselves am I interested in this, am I wondering about this, and then, they would think what has human beings already known about this, so that they can further contribute, like, and how can I change this?” (Classroom recording transcript, 2018/03/19)	MT
		▪ “Does innovation need to be something completely new? It must be something that no one has heard before? . . . Are people, scientists and engineers still design new cars? . . . Do you think the new cars are innovations or not?” (Classroom recording transcript, 2018/03/16)	other
Justifying Claims with Evidence and Reasoning	The necessity of evidence	▪ “We are trying to make our arguments very strong, right? Then, what could be your thinking process of preparing the pitch, making your argument very strong?” [students answered that they needed evidence] (Classroom recording transcript, 2018/03/21)	Q&P
		▪ “if I am doing my pitch, I will first think about a topic that really interest me and using sufficient and good evidence to prove and persuade other people that my technology is good for pursue.” (Classroom recording transcript, 2018/03/21)	MT
		▪ “Information! For sure! Ultimately your pitch, your argument is going to convince the panel … with all the helpful information you have, which is your evidence” (Classroom recording transcript, 2018/03/21)	other
	The sufficiency of evidence	▪ “Yeah, more reasons, like sufficient reasons, right? Sufficient evidence to prove your technology is good. It is important for sure!” (Classroom recording transcript, 2018/03/21)	other
		▪ “When I am doing it, I will also think questions like … ‘do I have enough evidence?’ … This my way of thinking of preparing my pitch, developing my argument.” (Classroom recording transcript, 2018/03/21)	MT
	The reliability of evidence	▪ “we use information from reliable sources to support our design … to make our design both innovative and also realistic” (Classroom recording transcript, 2018/03/16)	other
		▪ “How about, let’s take Kelvin’s for example, my ideas [developing smoothies for astronauts] is great, because I love smoothies, persuading? What you think?” [students answered that they needed reliable evidence] (Classroom recording transcript, 2018/03/21)	other

		▪ "When I am doing it, I will also think questions like . . . 'is my evidence really good and from reliable sources?' . . . all the time. This my way of thinking of preparing my pitch, developing my argument." (Classroom recording transcript, 2018/03/21)	MT
	Evidence needs to make sense to other people	▪ "Make sense to other people, that is very important. You do not want to talk about something that no one can really understand, right? You want your audience to know it. This reminds me, like, when we prepare ours or listen to others', try to think, like 'will this make sense to other people?' 'does this make sense to me?'" (Classroom recording transcript, 2018/03/21)	Q&P
		▪ "When I am doing it, I will also think questions like … 'does it make sense to other people, my evidence and my explanation?' all the time. This my way of thinking of preparing my pitch, developing my argument." (Classroom recording transcript, 2018/03/21)	MT
	The relevance of evidence	▪ "What do you think [asking other students]? You need to buy my technology, because it is good, it has so many functions. Or, let us rephrase it, do you think the 'so many functions' are really related, really relevant to the decision of buying it? Is this persuading?" (Classroom recording transcript, 2018/04/09)	other
		▪ "Remember, we have audience, we try to think how they would think to make their decision, right? . . . The "it is good" part is important, but, like, provide more information about why they need it, what your technology can bring them, etc., that will make all your evidence more relevant to your claim." (Classroom recording transcript, 2018/04/09)	MT

Notes:

Q&P—Questioning & Prompting (Argument-focused Metacognitive Scaffold);

MT—Modelling Thinking (Argument-focused Metacognitive Scaffold);

other—Scaffolds including metacognitive scaffolds in general (not particularly about argument or for argumentation) or scaffolds on the cognitive level, etc.

The second part of the NASA technology design project and scaffolds within it. The first focused activity, the NASA technology design project, had two parts, focusing on argument construction and argumentative dialogue respectively. After students completed their argument construction, they entered into the second part: presenting and communicating about their work (i.e., Q&A). Students presented their designed technologies, either within small groups or to the entire class, to persuade "the panel" that their technologies should be approved and supported by NASA. After each presentation, there was some time for Q&A. During the Q&A, the audience asked questions, gave comments, or expressed their different ideas, and the presenters responded to the audience. In this way, argumentative dialogues took place.

The teacher did some adjustments to that day's (2018/04/13) class schedule so that the class would have 150 minutes in total for the presentations. At the beginning of the class, before the presentations started, the teacher led a whole-class discussion (see Appendix D-5 for the full transcript and the researcher's analysis notes) talking with students about why they wanted to ask the presenters questions. They discussed that they would ask the presenters questions "to know more," to communicate, and "to help each other improve our work" (Line #07 to #12 in Appendix D-5). In addition, through *questioning & prompting* and *modelling thinking*, the teacher encouraged the students to monitor their own thinking and comprehension while they were listening to the presentations in order to come up with good questions. Ms. Bowen asked students, "How can we ask good questions to help each other? What could be your thinking process of asking a good question?" (Line #12). Then, based on students' responses, such as "you need to focus" and "pay attention," Ms. Bowen further prompted students to monitor their comprehension, saying that "maybe you could think 'do I understand this?' while you are listening to the presentation." She also modelled how to do that *monitoring*:

> Ms. Bowen: Like, later, when you present your technology, I will think "Do I understand his words?" 'He says he is going to send off his robots in this way, does this make sense?" . . . I will pay more attention on the part whether your evidence is supporting your claim, like, I won't judge if your design is, for example, good-looking or not. Or, your design is bad, you design smoothies for the astronauts, I do not like smoothies. [students laugh] But I care more about, hey, what is your evidence to prove that your technology is important? If you are designing smoothies, show me why it is important for NASA, right? Try to think like this while we are listening, like, try to monitor whether you are understanding or not. Asking ourselves, "Do I understand?" "What is the evidence?" "Is the evidence supporting?" Then, we will have very good questions to help your peers.
> (Classroom recording transcript, 2018/04/13; also shown in Appendix D-5 Line #15)

After this whole-class discussion, the teacher organized students to started their presentations. Some students preferred to present within small groups. These 12 students were divided into 3 groups by the teacher and shared their work with their group members, while the other 7 students presented to the whole class. Each student had around 12 minutes, 6 minutes for sharing their work and 6 minutes for the Q&A. The group sharing took place first. Students who were going to present to the whole class could join the group presentations if they wanted or they could continually improve and prepare their own presentations.

Most of the students' presentations included two parts: a transcript of their speech, usually including all the words they wanted to speak to the audience, and a blueprint of their technology design, which was usually a drawing. Students wrote and developed their transcripts (i.e., the writing) with Google Docs or Google Slides. Some of them drew the blueprints of their designs with Google Drawings and others used pencil and paper. What follows are two examples of students' work (Figures 4.1 and 4.2). The first one is part of Nate's presentation: the design of his AAA-31 robot (Figure 4.1 a-c) and spaceship (Figure 4.1 d). The second one is Jayraj's presentation of his rover, including a transcript of his speech and his blueprint.

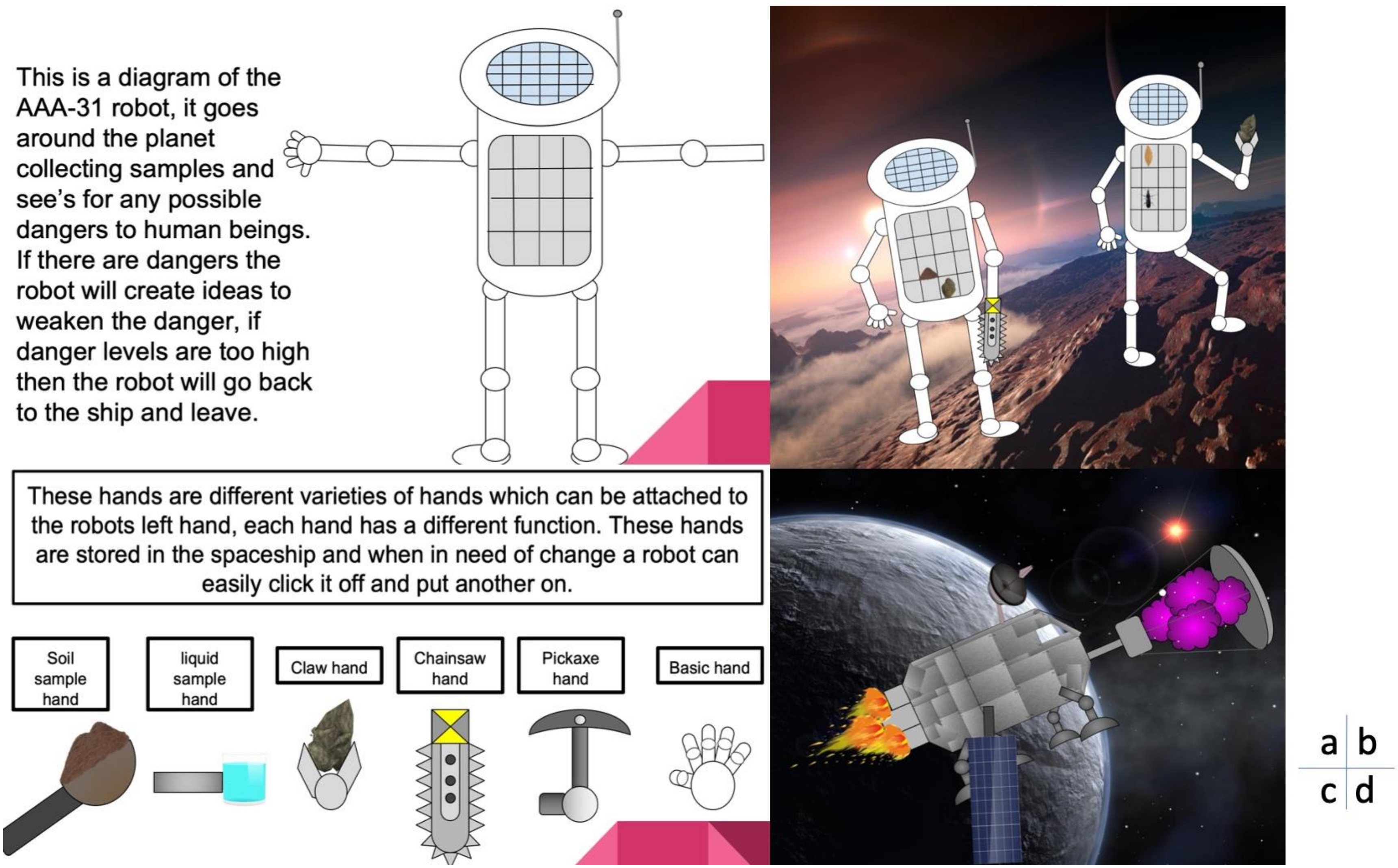
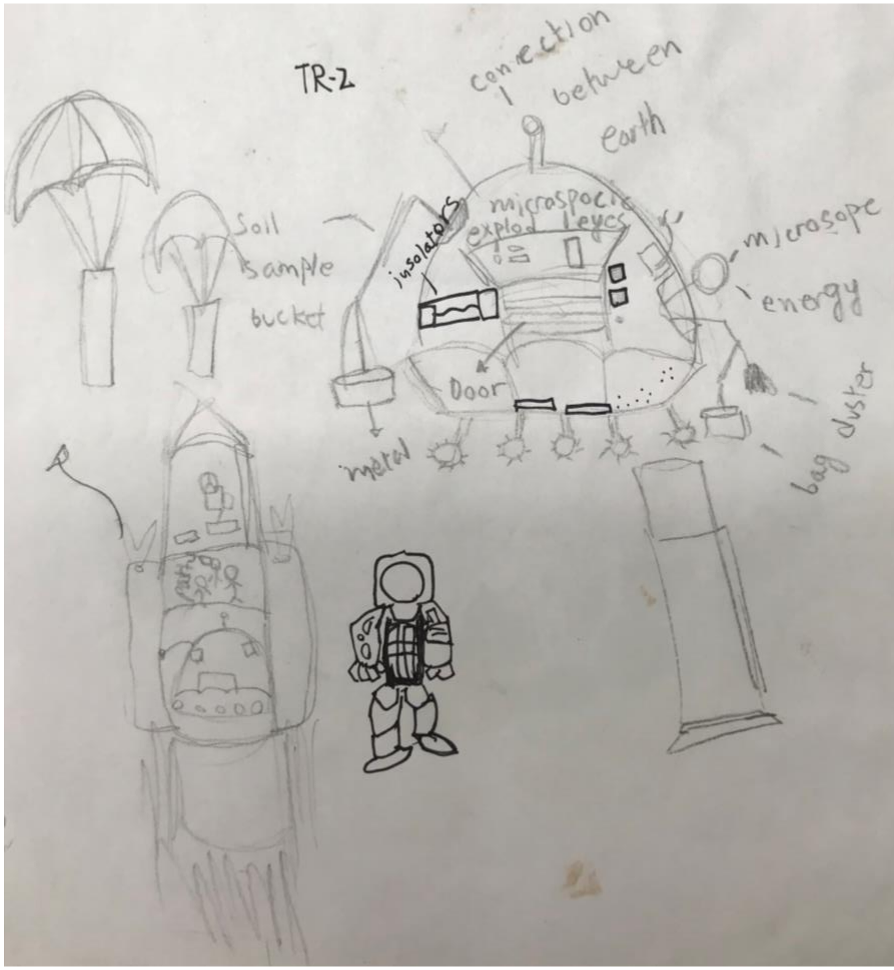
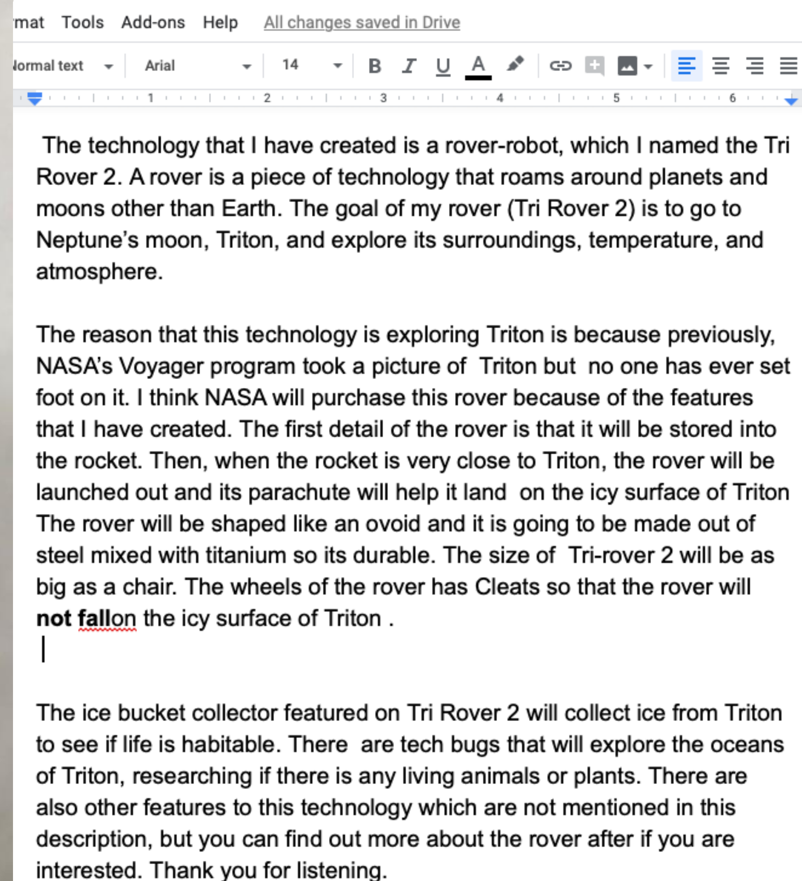


Figure 4.1 Nate's design of his robots and spaceship.





The technology that I have created is a rover-robot, which I named the Tri Rover 2. A rover is a piece of technology that roams around planets and moons other than Earth. The goal of my rover (Tri Rover 2) is to go to Neptune's moon, Triton, and explore its surroundings, temperature, and atmosphere.

The reason that this technology is exploring Triton is because previously, NASA's Voyager program took a picture of Triton but no one has ever set foot on it. I think NASA will purchase this rover because of the features that I have created. The first detail of the rover is that it will be stored into the rocket. Then, when the rocket is very close to Triton, the rover will be launched out and its parachute will help it land on the icy surface of Triton The rover will be shaped like an ovoid and it is going to be made out of steel mixed with titanium so its durable. The size of Tri-rover 2 will be as big as a chair. The wheels of the rover has Cleats so that the rover will **not fall**on the icy surface of Triton .

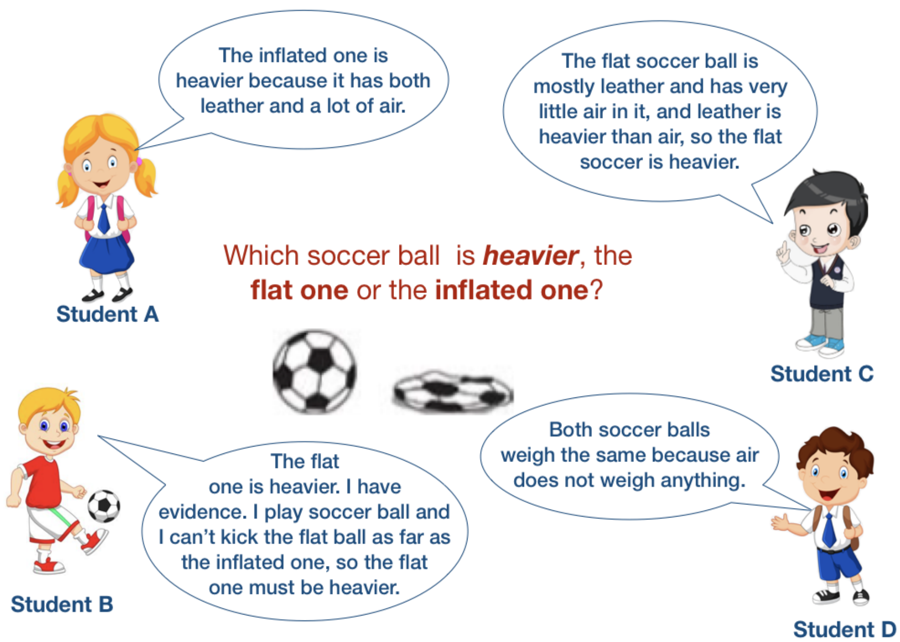
The ice bucket collector featured on Tri Rover 2 will collect ice from Triton to see if life is habitable. There are tech bugs that will explore the oceans of Triton, researching if there is any living animals or plants. There are also other features to this technology which are not mentioned in this description, but you can find out more about the rover after if you are interested. Thank you for listening.

Figure 4.2 Jayraj's design of his robot and rover.

After the presentations, students were asked to complete a self-assessment, which was designed by the teacher for the classroom assessment purpose. The self- and peer-assessment worksheet included four questions: (1) How successful and effective do you feel your pitch was? Explain what went well, what was challenging, and how convincing you think you were and why. (2) What could you do to improve your pitch even more? (3) Which question from the class made you think the most about your invention and how you could make your idea even better? (4) From watching others in the class, which pitch do you think was very convincing and well developed and why?

Thus far, I have described how the first focused activity (i.e., the NASA technology design project) was implemented in Ms. Bowen's science classroom, as well as what Ms. Bowen's scaffolds, including the argument-focused metacognitive scaffolds, looked like during this activity. As this NASA project completed, the class finished the first learning unit and entered into the second (i.e., air and aerodynamics) and third one (i.e., flight).

The second focused activity: Evaluating arguments about the air's weight. The teacher combined the second and the third units in her teaching. In the middle of learning these two units (see Table 3.1) and after they had learned the properties of air (e.g., air has weight and mass), the second focused activity designed in this study was implemented, which was an argument evaluation task (shown in Appendix E) focusing on students' argument evaluation. This task had two parts. In the first part (see below in Figure 4.3), students were asked to choose the most convincing argument from four, which were trying to answer the question "Which soccer ball is heavier, the inflated one or the flat one?" These four arguments had different claims and corresponding evidence. For example, student A (i.e., the first argument) thought the inflated soccer ball was heavier than the flat one, while other students had different ideas supporting either the claim that the flat soccer ball was heavier or that there was no difference, and all of them had their own supportive evidence. In the second part (as shown below in Figure 4.4), one argument from the first part (Student A) and another new argument (Student E) were presented to students. These two arguments had the same claim (i.e., the inflated soccer ball is heavier than the flat one), but different justifications with different evidence. Students were asked to decide which one was more convincing. In both parts, besides the choices, students were also asked to explain the reasons for their decisions and describe their thinking processes of making their choices.



- **Which student's argument do you think is the most convincing? And why?**

I think Student ____ is the most convincing.

Because____

____

____

- **Try to describe the thinking process of how you made this choice.**

____

____

____

Figure 4.3 Arguments and questions in the first part of the argument evaluation task.

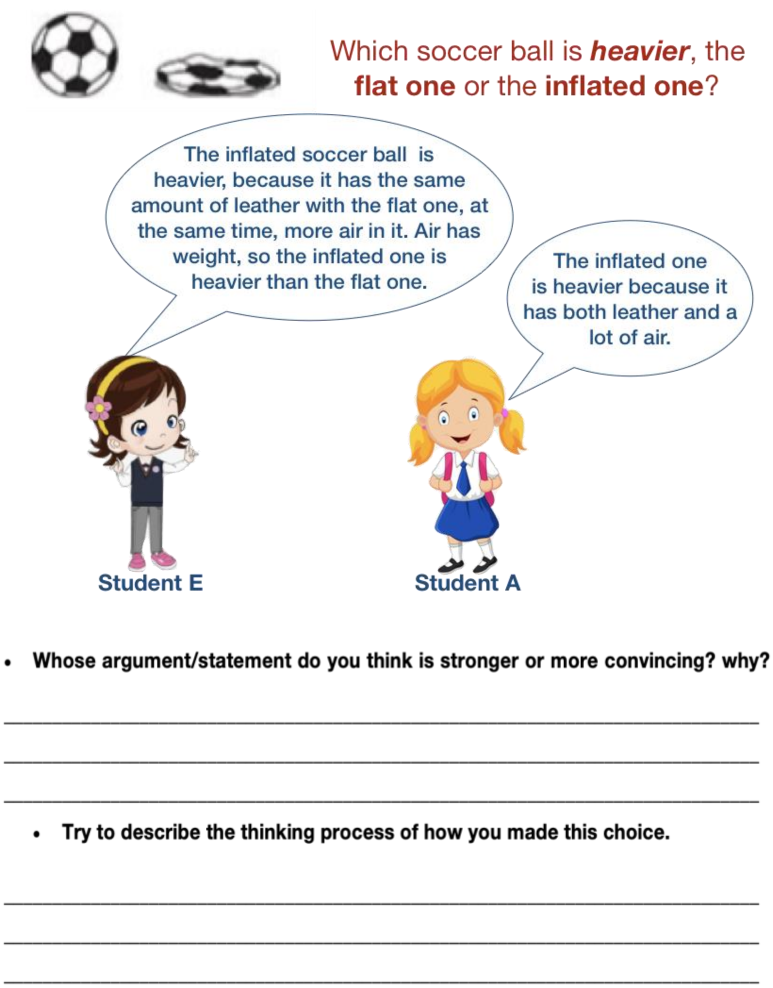


Figure 4.4 Arguments and questions in the second part of the argument evaluation task.

The third focused activity and scaffolds within it. At the end of the second and third learning units, the third argument-focused activity (i.e., parachute & glider design, testing, and improving) was designed to facilitate students to meet the "specific learner expectations" in the provincial curriculum: "conduct tests of model parachute design and identify design changes to improve the effectiveness of the design" and "conduct tests of glider designs; and modify a design so that a glider will go further, stay up longer or fly in a desired way; e.g., fly in a loop, turn to the right" (Alberta Education, 1996, p. B.31). In this activity, students worked on the parachute first in small groups (6 groups with 3 to 4 students in each group) and then worked individually on the glider. The teacher divided students into small groups according to their “[academic] performance” and previous collaboration experiences. Specifically, “some of them have worked [as a group] before on other projects,” so the teacher intentionally grouped students who had not worked together as a group, because she thought “they need to learn how to work with different people” (conversation with the teacher, 2018/05/28).

In the parachute part, students first learned the purpose of a parachute, which is, using students’ words, “to send something to the ground in a safe way” (Henry). Then, the teacher introduced components of parachutes, including canopy, shroud lines, and the weight. They also discussed how a parachute works through “decelerating and landing very very slow” (Xander) (classroom recording transcript, 2018/05/25). Then the teacher introduced the parachute model design activity. In this activity, students were asked and supported to design, test, and improve their parachute models, to make their models strong and of good quality (Alberta Education, 1996). They decided to do the final test with quail eggs, that is, a quality parachute (model) should safely land quail eggs from the second floor of their school building. They also discussed some criteria, such as the egg could not have any armour, they could not have real quail eggs for testing until the final testing day, the final testing would start with landing one quail egg and then they would increase the number of eggs, etc.

To engage students in argumentative practice while they were solving problems as a group, students were required to make decisions about and achieve consensus on every aspect of their designs (e.g., materials, size, shape) before they started building and testing. Specifically, they were provided with and asked to complete a planning document before they could get the materials that they needed to build their parachute models. The planning document was developed by the teacher and available on their Google Classroom, to which every student had access via their Chromebooks. The document included the following questions:

(1) Group members: __________________
(2) Material for the parachute canopy: ___________; Why we chose this material: ________________________
(3) Dimensions (size and surface area) of the canopy: ____________; Why: __________________
(4) Number of the shroud lines: ___________; Why: _________________________
(5) Length of the shroud lines: ________; Why: _________________________
(6) Sketch of prototype.
(classroom materials, 2018/05/25)

Students could use their Chromebooks to access online information for their evidence searching and decision making. While Ms. Bowen was introducing this planning document, she also emphasized that students would have opportunities to revisit the planning document and revise their design:

> Ms. Bowen: . . . this is only the initial ideas about your design, you can revise it after your testing. If you think this material, for example, the tissue paper does not work very well, you can revise it and try some other materials, maybe the garbage bag, right? So, this is for you to write down and decide your initial designs, ok?
> (Classroom recording transcript, 2018/05/25)

Students were asked to collaborate with peers in small groups to do inquiry activities solving science- and technology-related problems. Thus, Ms. Bowen's metacognitive scaffolds in the third focused activity had more emphasis than her previous scaffolds on resolving differences through discussion. Before students were dismissed into small groups to design their parachute models, Ms. Bowen initiated a whole-class discussion around how to collaborate and work together with peers (see Appendix D-5 for full transcript and the researcher's analysis notes). Through *questioning & prompting*, Ms. Bowen explicitly asked students how they would think and do when they had different ideas within their groups (Line #01). With all their previous learning experiences (e.g., experiences of constructing arguments during the first focused activity), students explicitly expressed that they could discuss their various ideas and compare and examine their evidence to make their final decision. Specifically, David said "everyone in the group should have the chance to express . . . say this is what I think, and this is my evidence . . . and we, as a team, compare the evidence, and make our decision" (Line #04). Ivan also expressed the similar idea that they "can take the turn to say [their] ideas . . . and reasons" because discussion with reasons and evidence was a good way to resolve differences (Line #05). Then, the teacher confirmed those ideas, emphasizing the importance of discussion and evidence through modelling how scientists would think and do when they had different ideas. Ms. Bowen said, "evidence and reasons are always important . . . we communicate with evidence and respectfully, just like how scientists do and think" (Line #06).

After this discussion, students started to work in small groups to complete their planning document about parachute design and do the building, testing, and improving. When the teacher joined groups, she provided scaffolds. For example, through *questioning & prompting*, Ms. Bowen asked questions such as "Why do you think this design works well? What is your evidence?" and "Now you have different ideas [Luis wants to use a garbage bag and Xander and Nadia want to use a balloon to make the canopy], right? Let us share how you think" to draw students' attention to the evidence (Classroom recording transcript, 2018/05/28).

The next week, the students did their final testing of their parachute models. After the testing, the teacher invited students to complete the self- and peer-assessment she had developed for the classroom assessment purpose, which included the following questions: (1) List some observations you made about the success of your parachute. What specifically would you adjust (canopy, shroud lines, basket) to make it even better (able to hold more weight, longer air time . . .) (2) Pick one or two parachutes that your group did not make, but you thought worked well. What was special about their design that made them work well? What would you specifically adjust to make them even better?

In this chapter, I described the focused activities in this study, as well as what the argument-focused metacognitive scaffolds (i.e., *questioning & prompting* and *modelling thinking*) and other scaffolds looked like and how they were implemented and embedded in the classroom science teaching. This chapter described the specific context in which this research took place. In the next chapter, I present the study's main findings regarding students' metacognition and argumentation in this particular context.

CHAPTER 5

FINDINGS

The purpose of this study was to explore students' Mc-A (metacognition in the context of argumentation) in a science classroom setting with argument-focused metacognitive scaffolds integrated into the teacher's classroom instructions. Specifically, this research aimed to investigate how students' Mc-A manifests and how it is involved in argumentation in science classrooms with argument-focused metacognitive scaffolds.

As describe in Chapter 4, the three focused classroom activities in this study had different focuses (i.e., argument construction, argument evaluation, and argumentative dialogue), as did the teacher's scaffolds in these activities. The first focused activity (i.e., NASA technology design project) consisted of two parts. Part one of this design project and the teacher's scaffolds within it focused on students' argument construction. Part two and the teacher's scaffolds within it focused on students' argumentative dialogues. The focus of the second activity was argument evaluation. The third activity and the teacher's scaffolds within it focused on students' argumentation dialogues in a group problem-solving context. Due to the various focuses and characteristics of the activities and the teacher's scaffolds within them, some differences would be expected in students' Mc-A in these different kinds of argumentative practices. For example, how students' Mc-A was related to their argument construction might be different from how it was related to their argument evaluation. Therefore, in this chapter, I describe students' Mc-A in these different kinds of argumentative practices in the order of lesson development during the research period, that is, (1) argument construction in the NASA technology design project and argumentative dialogues during the activity, (2) the argument evaluation task, and (3) argumentative dialogues in group problem-solving contexts.

Presenting results in this way, however, does not mean I see or think of these three forms of argumentative practices (i.e., argument construction, argument evaluation, and argumentative dialogue) as exclusive or independent of each other. Rather, I believe that the connections and interactions among them are evident and necessary. For example, during the argumentative dialogues, almost each and every move (e.g., raising counter-claims, accepting or rejecting certain pieces of evidence or the entire argument) was based on students' evaluations of their own and their peers' argument construction. In other words, both construction (i.e., construction of their own arguments) and evaluation (e.g., evaluation of others' arguments) were involved in argumentative dialogues. In addition, while the students were constructing their own arguments, they were supposed to evaluate such things as whether they had sufficient and relevant evidence to support their own claims or whether their justifications made sense to other people, etc., and then to determine what they could do next. Therefore, these different forms of argumentative practice are closely interrelated. However, I decided to describe the students' Mc-A in these activities separately because this way allowed me to better explain whether and how students' Mc-A was related to the teacher's instructional scaffolding in each activity, as well as further potential pedagogical contributions of the scaffolding in this study.

As I reflected in the Methodology and Methods chapter, my knowledge, beliefs, and thus inference on metacognition was involved in interpreting students' Mc-A in this study. Therefore, whenever I state in this thesis that students' Mc-A manifested, it actually means that indicators of students' Mc-A were discerned based on my inference. This is because the presence of metacognition, such as Mc-A in this study, which is an inner mental awareness or process, usually cannot be directly observed but only inferred (White, 1998, as cited in Thomas, 2012).

In this chapter, the themes or patterns, which emerged during the data analysis, were commonly found across data sets (i.e., sub-clusters of data in this study); therefore, are reported as the main findings of this study. However, because it is not possible or necessary to present all the supportive data sets, distinctive exemplars were selected to illustrate the findings. Usually, 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 18 students), or, specifically, "cases within the case" (Stake, 2000, p. 447), that is, students who were closely observed and interviewed in this study. Thus, in this chapter, the main findings are all illustrated with selected distinct examples as the supportive evidence.

5.1 Argument Construction in the First Focused Activity

In this section, I describe how students developed their own arguments, how their Mc-A was related to argumentation construction, and how students thought about their Mc-A. Data analysis revealed that students' Mc-A, both the knowledge aspect (i.e., McK-A: metacognitive knowledge specific to argumentation) and the regulation aspect (i.e., McR-A: metacognitive regulation in the context of argumentation), was involved in their argument construction. Students' Mc-A was related to their decision making regarding how they would do and think while they were constructing their own arguments about the space exploration technology. Students' Mc-A mainly manifested (both concurrently and retrospectively) within the interviews with them, in which their thinking processes of argument construction were talked about explicitly. The interviews included the in-class informal interviews and the SRIs (stimulated recall interviews), as well as the semistructured interviews at the end of the research period. During these interviews, whenever I noticed students' Mc-A showing up (i.e., when I realized possible indicators of students' Mc-A), I would invite them to further share how they thought about their Mc-A. With these data, it was found that, at this stage (i.e., the first focused activity), students tended to relate and attribute their Mc-A to the teacher's instructional scaffolds.

Further examination of the process of students' argument construction revealed that how individual students constructed their arguments, in which their own Mc-A was involved, was diverse, yet had something in common. In what follows, I describe similarities in how students initiated their argument construction, such as with the shared goal (i.e., "to persuade"), and framed their claims, and diversity in how they further developed their arguments, for example, using different strategies to find evidence to justify claims.

5.1.1 Argument Construction with Knowing the Goal: "To Persuade"

During the first focused activity, students were supported to construct their own arguments. They designed their own technologies for NASA's future space exploration and then presented their designs to the panel of their "coworkers from NASA." With the aim to get their technologies approved and supported by NASA, students therefore needed to prepare and construct a strong argument to persuade their classmates. According to what the teacher shared, students had not participated in any argument-focused activities before. Thus, it took the teacher and students some time to initiate the argument construction. At this initiation stage, which the teacher also called the "start-up stage," the teacher was aiming to support students to, using her own words, "learn, accept, and understand the goal of this project [argument construction], realize and accept the importance of evidence, and have their claims ready" (informal conversation with the teacher, 2018/03/14).

At the beginning of this activity (science class on 2018/03/14, see Appendix D-1 for the full transcript), Ms. Bowen built a scenario in which all the students were innovative technologists at NASA. Through *questioning & prompting*, *modelling thinking*, and other scaffolds, the teacher facilitated her students to understand that the goal of their arguments, which they called a pitch, was "to persuade." This goal was continually confirmed and emphasized by the teacher in subsequent classes (e.g., science class on 2018/03/16 and 2018/03/21).

Students I interviewed (both formally and informally) understood "to persuade" as the goal of their argument construction, and they considered how to achieve this goal while they were making decisions regarding how they would do and think during their argument construction. In this way, being aware of the goal of their argument construction, as their conditional McK-A, was involved in their argument construction. What follows is an illustrating example.

Example #01: Zhao knowing the goal of his argument construction

In the second class during this project (science class on 2018/03/16, shown in Appendix D-2), after the teacher-led whole-class discussion, students were dismissed to do their online research individually to decide what technologies they wanted to pursue and to frame their claims. During the classroom observation, I noticed that Zhao only explored NASA's information, including NASA's websites and YouTube channels, and occasionally copied and pasted some information from the website into his Google slides. To learn how he thought, I initiated an in-class informal interview with him:

> Researcher: Why are you particularly using the information from NASA? You are, right?
> Zhao: . . . yes . . . this is NASA's website.
> Researcher: What are you thinking when you particularly use NASA's information?
> Zhao: You know, I need to persuade NASA to buy my technology, so I am thinking using the information from their website is good, this is [pointing to the content on the screen with his finger] what they are talking about and what they are doing right now. . .
> Researcher: Why do you need to persuade NASA?
> Zhao: We all need to persuade the panel, like we talked in the class . . .
> Researcher: You mean you know this from your classroom discussion?

> Zhao: . . . yes, you were here, Ms. Bowen told us it is a pitch, and we all agreed, and it just makes sense, like, to prove and to persuade, like, we are all the NASA guys . . .
> (In-class informal interview transcript, 2018/03/16)

Zhao was aware that the goal of his argument construction was "to persuade." With the aim to achieve that goal, he regulated his cognitive actions through particularly exploring NASA's information sources, because he thought using NASA's information "[was] good." In this way, Zhao's awareness of the goal of his argument construction (i.e., conditional McK-A about the goal of argumentation) was involved in his argument construction. He started his argument construction knowing the goal and thinking about how to achieve this goal. Moreover, during the interview, he also shared that he knew the goal because they "talked in the class." According to what he shared, he remembered what "Ms. Bowen told" the class and what was agreed by the class, which also made sense to him, so this goal was reflected in his argument construction. In this way, within the in-class informal interview, in which we explicitly talked about his thinking process, Zhao demonstrated that his McK-A was involved while he was constructing his argument. Moreover, he related and attributed his McK-A to his classroom learning, particularly what and how the teacher had taught them.

5.1.2 Argument Construction with Knowing How to Frame Claims

After students understood that the goal of their argument construction was "to persuade," the teacher led the students to move to the next step, which was to frame their claims. As described in Chapter 4, students' claims in this project shared the format of "NASA should approve and support my technology: _____________." Thus, framing the claim in this project was deciding the technology they wanted to design and pursue. To support students to frame claims (i.e., to think about specific technologies that they wanted to pursue), on the second class within this focused activity (science class on 2018/03/16, see Appendix D-2 for the full transcript), the teacher initiated a whole-class discussion about how to think to generate "both innovative and realistic" topics. Through modelling the thinking process, the teacher introduced a way of thinking to develop "both innovative and realistic" technologies. To be specific, the teacher encouraged students to connect their personal interests with their knowledge about current space research. For example, the teacher modelled the thinking process, saying:

> Ms. Bowen: . . . [you think about] your personal interests [first], [then] you think how to connect that with the space, this is the innovative part, right? Then, you might think to start your research, you find what people have already known about his topic, how you can improve it or make it better . . .
> (Classroom recording transcript, 2018/03/16; also shown in Appendix D-2 Line #27)

(See Appendix D-2 for more information about the scaffolds the teacher used.) This way of thinking was further confirmed and emphasized by the teacher in subsequent classes (e.g., science class on 2018/03/21 and 2018/04/06).

Students, at least the ones I interviewed, responded positively to the teacher's scaffolds. According to what students shared during the interviews, they took the teacher's suggestion and thought about their topics through deliberately connecting their personal interests and their knowledge about current space exploration. Students' conscious adjustment of their own thinking during argumentation is defined in this study as *metacognitive control*, which is one of the two components of McR-A (McR-A includes *metacognitive monitoring* and *metacognitive control*). In this way, students' metacognitive control was involved in their argument construction as they consciously adjusted their way of thinking to generate "both innovative and realistic" technologies (i.e., to frame their claims). Students were also aware of how they learned this way of thinking, as they clearly related knowing this way of thinking to the teacher's scaffolds. What follows is an illustrating example.

Example #02: Henry adjusted his way of thinking to frame his claim

Two weeks after the teacher-led whole-class discussion about the way of thinking to frame their claims, Henry volunteered to share his work with his classmates. After he introduced his technology, which was to design a space soccer field (he changed his topic later to "a space sport centre"), Ms. Bowen asked him "Why are you working on this topic, the space soccer field? How did you generate this topic and frame your claim?" Henry replied:

> Henry: Soccer inspires me and I am obsessed by it . . . so I went to search to see if I can find any information or knowledge related to soccer and space, then, I found that in 1996 NASA was thinking of making an Olympic centre on the moon. They said they would achieve that in 2010, but sadly they changed their mind . . . now I am going to bring this idea back, but with better ideas in my space soccer field . . . not limited to the moon, but to travel in our galaxy . . . it is from my personal interest, and also based on my knowledge from researching on NASA's website . . .
> (Classroom recording transcript, 2018/04/06)

With these words, Henry shared how he framed his claim. His response was interpreted as a possible verbal indicator of his metacognitive control, because it indicated that he could adopt the way of thinking that the teacher had modelled and discussed with them and that he had generated his topic by deliberately synthesizing his personal interests (i.e., soccer) and his online research into NASA's space exploration.

During the SRI with Henry, I showed him the video clips of the conversation with Ms. Bowen above. After that, we talked about his thinking process of generating his topic and how he learned that way of thinking.

> Researcher: Can you share a bit about your thinking process of developing your topic?
> Henry: . . . Like I said, I love soccer, that is my personal interest, I think first. Then I did my research. I found NASA's old project . . . mine is better, that is how I improved it and why NASA should approve my space centre.
> Researcher: So, you thought your personal interest first.
> Henry: Yeah, first, think, thought about my personal interest, then think like how I can connect soccer with space, that is the most difficult part . . . I asked my dad, he said no, no connection . . .
> Researcher: How did you learn this way of thinking? This is a new way of thinking, generating the topics, right? Have you tried this before?

Henry: Yeah, it is new . . . needs to be innovative and realistic, you know, they are usually [he stopped]
Researcher: Usually conflicting with each other, right?
Henry: Yeah, conflicting with each other. So, it's new. But, Ms. Bowen told us that is the way we can generate a both innovative and realistic technology, and I agree, like, I also think so. So, I tried.
Researcher: You think it worked well, I mean this new way of thinking and doing? Is it difficult to perform, to use, to think in this way?
Henry: It works well, I think. In this way, my space centre is very convincing . . . I really improved NASA's project . . . not very difficult, but the connection part is really hard, you really need to search and research around to find the connection . . .
(SRI transcript, 2018/06/18)

During the interview, when I explicitly enquired into his thinking process, Henry described how he thought in order to frame his claim: "first, think . . . about [his] personal interest, then think . . . how [he] can connect soccer [his personal interest] with space." He also shared that he knew this way of thinking "is new" and further explained that even if he never thought in this way before, "but, Ms. Bowen told [them] that is the way [they] can [think to] generate a both innovative and realistic technology, and [he] agree[d] [with what Ms. Bowen said] . . . so [he] tried [this new way of thinking]." That is, he learned how to adjust his thinking based on his teacher's scaffolding. Through comparing the interview with the classroom observation, it was found that what Henry shared during the SRI was consistent with what he had said during the in-class conversation with the teacher. During the interview and class conversation, it was clear that his metacognitive control was involved in the process of framing the claims.

5.1.3 Argument Construction with Knowing the Necessity and Importance of Evidence

After students accepted that the goal of their argument construction was "to persuade" and had framed their own claims, Ms. Bowen further guided and facilitated students to consider how to persuade the NASA panel to accept their claims and how to make their arguments strong and convincing (science class on 2018/03/21, see Appendix D-3 for the full transcript). Ms.

Bowen employed *questioning & prompting* and *modelling thinking* in the teacher-led whole-class discussion to facilitate students to realize the necessity and importance of evidence. For example, using *questioning & prompting*, Ms. Bowen asked her students, “We are trying to make our arguments very strong, right? Then, what could be your thinking process of preparing the pitch, making your argument very strong?” In response to the teacher’s question, students said “supportive information helped to be convincing.” Then, building on students’ words, Ms. Bowen introduced her students to what “evidence” was, as well as the necessity and importance of evidence in argument construction:

> Ms. Bowen: Information! For sure! Ultimately your pitch, your argument is going to convince the panel . . . with all the helpful information you have, which is your evidence. Evidence is very important, actually the most critical part in your pitch . . . (Classroom recording transcript, 2018/03/21; as shown in Appendix D-3 Line #07)

The necessity and importance of evidence were also continually confirmed and emphasized in subsequent classes. For example, during the small-group sharing, the teacher always asked students questions about evidence, such as “What is your evidence?” or “Do you have any evidence to support your claim?” With these questions, the teacher reminded students to use evidence to justify their claims and helped students realize the necessity and importance of evidence.

Examining students’ arguments revealed that almost all the students supported their claims with evidence. Yet, the evidence they cited was different, in terms of how sufficient or relevant it was. Further analysis of their processes of constructing their arguments showed that students were aware of the necessity and importance of evidence while they were engaged in argument construction. Being aware of the necessity and importance of evidence (Mc-A), students knew they needed to do their “research” to gather evidence. In this way, it was found that their McK-A was manifested in their argument construction. Regarding their McK-A, students also attributed it to the teacher's scaffolds. What follows is an example illustrating how students' McK-A about the necessity and importance of evidence was involved in their argument construction, and how they related their McK-A with the teacher's scaffolds.

Example #03: Nate knowing the necessity and importance of evidence

During the SRI, Nate shared with me about his argument construction:

> Nate: . . . we discussed in class [that] good pitch is well, highly supported by lots of evidence, good evidence . . . I have lots of supportive information in mine. I did my research to find evidence, as I know I need evidence and evidence is important . . . (SRI transcript, 2018/05/04)

Nate was aware that, to be convincing, his claim needed to be "highly supported by lots of evidence." With this awareness, he deliberately "did [his] research to find evidence," thus "[had] lots of supportive information" in his argument.

Eager to learn more about how Nate knew about his McK-A about evidence, I asked him some follow-up questions to clarify what he meant by "discussed in class," and we had the following conversation during that interview:

> Researcher: . . . you mentioned that you know evidence is important because you discussed in class, right?
> Nate: Yes, [nodding] we discussed a lot about evidence.
> Researcher: What do you mean by "discussed in class"?
> Nate: Like, Ms. Bowen *showed* us. [he stressed the word in italics]
> Researcher: *Showed* or *told*? [I stressed the words in italics])
> Nate: *Showed*, not *told*, like *show*, not *tell*. [he stressed the words in italics]
> Researcher: Then, what do you think is the difference? [Do] you think there is difference [between showing and telling]?
> Nate: Showing is like, it is different from telling you, like, what you should do, or you should do this, you should do that, but, kind of explaining, yes, explaining. Ms. Bowen explained.
> Researcher: By giving you examples or asking you questions, right?
> Nate: [nodding] Yeah, the questions and examples and explanations . . . (SRI transcript, 2018/05/04)

During the SRI with him, Nate clarified that he knew his McK-A about evidence (i.e., declarative McK-A about the necessity and important of evidence) because the teacher had "showed" them. He also distinguished "showed" from "told" and elaborated that it was the teacher's "questions and examples and explanations" that helped him "know evidence is important." In other words, within this self-report interview, Nate attributed his McK-A about the necessity and importance of evidence to the teacher's classroom scaffolds.

With various scaffolds, the teacher continuously emphasized the important aspects of argumentation, such as persuasion with reliable information as evidence. Students thought and reported that these scaffolds affected their Mc-A, including their conditional McK-A about the goal of their argument construction, their metacognitive control of their thinking to frame claims, and their declarative McK-A about the necessity and importance of evidence. Moreover, data analysis revealed that these aspects of Mc-A were involved in students' actual argument construction, as students used their Mc-A to regulate their thinking and doing while they were engaged in argument construction. Thus far, with the teacher's instructional support, students had initiated their argument construction in a similar way, that is, students were all aware that they *needed evidence* to *persuade* their audience to accept their claims which were related to *both their personal interests and their knowledge about current space exploration*.

5.1.4 Argument Construction with Knowing What "Good Evidence" Is and How to Find It

As the project went on, the argument construction entered into the next stage, which the teacher called "the writing stage" or "the justifying stage." During this stage, students were encouraged to further develop their arguments by justifying their claims with evidence and reasoning. Before dismissing students to search and gather evidence to justify their claims individually, the teacher led the whole class to discuss what kinds of evidence were "good," how to find "good evidence," and how to better justify their claims. For example, at the science class on 2018/03/21 (see Appendix D-3 for the full transcript), in response to the teacher's *questioning*

& prompting, students mentioned that "good evidence" needed to be reliable and "make sense to other people," and that to better justify their claims they needed sufficient evidence. In subsequent classes, with similar scaffolds, Ms. Bowen continually facilitated students to think about and explicitly discuss how to find "good evidence" and how to better justify the claims. For example, during the classroom discussion in a later class, Nadia expressed what she thought about organizing various evidence to better support a claim: "to better support [that] your technology [should be approved and supported by NASA], instead of [presenting] many many reasons, you really want to say the ones which are really really important first" (Classroom recording transcript, 2018/04/04).

At this justifying stage, regarding what "good evidence" is, how to find "good evidence," and how to better justify a claim, the teacher-led discussions were *open ended*. In other words, the teacher did not explicitly define or explain to students what "good evidence" was or what *the* way to find "good evidence" was. What follows is an excerpt from the classroom discussion in which the teacher and students talked about good evidence:

> Teacher: Then, what is good evidence in your mind?
> Nate: Good evidence can be from research, something from experts and books and research.
> Ivan: Good [evidence], like, is what we learned from classes.
> David: Not necessarily to be from classes, but good evidence needs to be true . . . and make sense to other people.
> Teacher: Make sense to other people, that is important. You do not want to talk about something that no one can really understand, right? You want your audience to know it. This reminds me . . . [the teacher started to talk about how to monitor one's own comprehension]
> (Classroom recording transcript, 2018/03/21; as shown in Appendix D-3 Line #12 to #16)

As shown in this excerpt, students shared their ideas around "good evidence"; however, the teacher did not clarify or firmly summarize what "good evidence" was, leaving it open ended. Without clarification, however, in the next discussion, the teacher continued mentioning "good evidence." For example, she said to her students, "we need to persuade NASA that your idea is great with . . . *good evidence* . . ." and "if I am doing my pitch, I will . . . use *good evidence* to prove and persuade other people that my technology is good to pursue" (classroom recording transcript, 2018/03/21). Similarly, regarding how to find "good evidence" and how to better justify a claim, the teacher also encouraged students to think about and share, yet did not teach or tell them *the* way to find "good evidence" or *the* way to justify.

It was found that students were holding different declarative McK-A about what "good evidence" was and procedural McK-A about how to find "good evidence" and how to justify a claim. Their diverse McK-A was also involved in their argument construction, especially searching online and evaluating evidence to support their claims. In this way, students' argument construction, which was initiated in similar ways (e.g., knowing the same/similar goal and way of thinking to frame claims), developed in diverse manners. Regarding their diverse McK-A, students also tended to attribute it to the teacher's scaffolds.

In what follows, I describe three illustrating examples (i.e., Levi's, David's, and Jeff's argument construction) to explain how students' McK-A was different from each other's, how their diverse McK-A was involved in their own evidence searching and justification, and how they thought their McK-A was related to teacher's scaffolds.

Example #04: Levi's argument construction

The first excerpt is about Levi's argument construction. At their presentation day (i.e., 2018/04/13), Levi presented his technology to the entire class. After the presentation, Levi's argument (i.e., the transcript he wrote for the presentation) was brought back to him in the SRI. During the SRI, he shared with me his thinking process of constructing his argument. His argument and part of the transcript of the SRI with him are shown in Table 5.1 (see below, Table 5.1-1 and Table 5.1-2) with my analysis notes.

Table 5.1-1 *Levi's argument for his NASA technology design project*

Line #	**Levi's Argument** (Students' writing, 2018/04/13)	**Analysis Notes** (i.e., My Interpretation)
01	My project is the Solitude 1, a rover to explore Triton. It will advance NASA's research and improve mankind. It should be approved and supported by NASA.	Claim making
02	My technology is reasonable and very very helpful,	Sub-claim making
03	because it could solve a lot of problems by researching Neptune's biggest moon, Triton. A: If one day we want to pull it out of orbit and put it in the goldilocks zone, we could use its ice volcanoes for resources. Here is my theory: When we pull it out of orbit then its ice volcanoes would change into lava, so once it cools down, we could collect some valuable minerals … If we could research it we would see if there are chemicals we need to get rid of before we could live there. We could maybe discover a new element to add to the periodic table! B: Another reason why we should research Triton because . . . we don't have much information about it. Think: if we got a lot of information from the Voyager 2, then how much information would we get from this?	Evidence-based defending
04	Here is my plan of exploring Triton with Solitude 1, which is both innovative and realistic:	Sub-claim making
05	[showing his hand-drawing blueprint] Here is the insulation, a camera, a link, same on the other side. Here are its thrusters. This is a RTG (radioisotope thermoelectric generator), it takes in radiation and gives out electricity to fuel the thrusters. The radiation exits from this chunk of staple plutonium. This is hot water surrounded with a calcium tank. On top, it has a 360 camera and a signal.	Evidence-based defending

Levi's design was a rover, which he named "Solitude 1," to explore the Neptunian moon Triton. Thus, the claim of his argument was "[Solitude 1] should be approved and supported by NASA" (Line #01). That general claim has two parts, which were justified with their corresponding supportive evidence. The first sub-claim was that his technology "is reasonable and very very helpful" (Line #02). The second sub-claim was "Solitude 1 . . . is both innovative and realistic" (Line #04).

Table 5.1-2 *Levi's self-reported thinking process of constructing his argument*

Line #	**Transcript of SRI with Levi** (SRI transcript, 2018/05/04)	**Analysis Notes** (i.e., My Interpretation)
	Researcher: Can you share with me your thinking process of developing the Solitude 1?	
06	When I did my research on Triton, I found, like, the most challenging thing is there is very limited, like little information about it [Triton]. The only thing we knew about Triton is from Voyager 2, which is just passing by the Triton . . . I cannot find my evidence [about Triton] from the online research.	Ongoing evaluation of and reflection on his online evidence searching
07	So, I need to use my logic to make evidence to prove that . . . [I need to] logically explain how my technology is reasonable and helpful . . . [and] why NASA should support a technology to explore Triton . . . Ms. Bowen gave me the tip [to use my logic] . . . I used my logic to develop the information I found on NASA's website . . . and [the information included in] the videos Ms. Bowen showed us [into evidence] . . . to prove my technology is reasonable and helpful to not only NASA but also our human society.	Indicator of *procedural McK-A* [knowing how to find/generate the relevant evidence he needed] Indicating that he learned this (i.e., how to generate relevant evidence) from the teacher
08	Then . . . I use my imagination and the information from NASA to design Solitude 1 . . .	
09	. . . I think information on NASA's website is reliable.	Indicator of *procedural McK-A* [knowing how to find valid evidence]
10	You do not want to use something wrong as your evidence . . .	Indicator of *declarative McK-A* [knowing "good evidence" needs to be valid]
11	. . . being valid is important, like I said, I do not want anything wrong as my evidence, that is important, the other thing I think, it should be related to your topic.	Indicator of *declarative McK-A* [knowing what "good evidence" is, "good evidence" should be valid and relevant]

12	For mine, I need the evidence is really about Triton, but there is no information, little information online is really about Triton, so, like I said, I need to use my logic . . .	Indicator of *procedural McK-A* [knowing how to find/generate the relevant evidence he needed]
13	I mainly use NASA's website, because it is more reliable, and, we are designing technology for NASA, so it is also, all related . . . I think they won't post fake information on their website . . .	Indicator of *procedural McK-A* [knowing how to find valid and relevant evidence]
	Researcher: How do you know this? How do you know that evidence should be valid and related to the topic?	
14	. . . how I know it . . . it is just . . . you cannot use anything wrong, that is not convincing, remember, we need to persuade, if you use something wrong, and when people find it [is wrong], then, that is not good . . . and if you just say . . . something which is [not relevant], that is not convincing as well, people will find it and ask "what are you talking about? That is not related at all!" you do not want your coworkers or people from NASA say that . . .	He explained how he thought about his McK-A; he related "*evidence needs to be valid and relevant*" to "*the goal of argumentation is to persuade the audience*"

According to what Levi shared during the SRI, his knowledge about what "good evidence" was and how to find it was involved in developing his argument. He knew that "good evidence" needed to be both relevant and valid (i.e., declarative McK-A about what "good evidence" is), and he also knew his own strategies to find the "good evidence" he needed (i.e., procedural McK-A about how to find "good evidence") and applied these strategies while he was constructing his argument.

Through evaluating his own online evidence searching, Levi realized that there was little information available online about Triton that he could use as evidence (Line #06, #12). In other words, he realized that online searching could not provide him the relevant evidence he needed, which was "really about Triton" (Line #12). Accordingly, he decided to "use [his] logic" to generate relevant evidence from what he found online and what he had learned from previous classes (Line #07, #12); that is, he knew how to generate the relevant evidence he needed (i.e., procedural McK-A) and he did so. Regarding how he knew this strategy (i.e., "us[ing] logic" to generate evidence), he further elaborated that it was because "Ms. Bowen gave [him] the tip" (Line #07), attributing his McK-A to the teacher's support. To be specific, based on the limited information about Triton he found on NASA's website (i.e., that there are many ice volcanoes on the surface of Triton), he proposed that human beings could use "[Triton's] ice volcanoes for resources . . . if we could research it" (A in Line #03). From the video that Ms. Bowen showed them, Levi had learned that "the only thing we knew about Triton is from Voyager 2, which is just passing by Triton" (Line #06), thus, he excitedly suggested that his technology, which was aiming to explore Triton directly and particularly, would bring human beings much more information about that Neptunian moon (B in Line #03). These two reasons (A and B), which derived from his logical inference, were the main reasons he gave in the first part of his argument for why human beings should research Triton. With these pieces of evidence, which were "really about Triton," he supported and justified that his technology choice would be "reasonable and helpful to not only NASA but also our human society" (Line #07).

In addition to being relevant, Levi also knew that evidence needed to be valid (Line #09, #10). To find valid evidence, his strategy was "mainly us[ing] NASA's website" because he thought "[NASA] is . . . reliable . . . and won't post fake information on their website" (Line #12). Thus, in the second part of Levi's evidence-based defending, he used "[his] imagination and the information he found from NASA to design Solitude 1 [his technology]" (Line #08) and to support his claim that his technology was "both innovative and realistic" (Line #04). Using his imagination, he designed his rover with many parts with different functions, such as gathering samples and images and sending data back to Earth (Line #05). With these specific designs as the evidence, he justified that his rover, Solitude 1, was "innovative." At the same time, according to his online research, his rover was powered by a new and real technology recently invented by NASA (i.e., the radioisotope thermoelectric generator [RTG] Levi mentioned in his argument [Line #05]). He connected and included the information he found on NASA's website, which he believed to be valid (Line #13), into his technology design, and he used that information as evidence to justify why his technology was "realistic."

During the SRI, when Levi was asked how he knew his knowledge about evidence, he connected what he knew about evidence to both the goal of argument construction and the existence of the audience. According to what he shared, he knew his presentation would have an audience and he wanted to persuade his audience. Therefore, he knew that he needed valid and relevant evidence, otherwise his presentation/argument would not "[be] convincing" (Line #14). Levi explained that his knowledge about evidence (i.e., McK-A about what "good evidence" is) was related to the requirements and characteristics of this particular project, which was designed by the teacher as part of her classroom instruction. In this way, according to what Levi said, his McK-A was also related to the teacher's instructional supports.

Analysis of the process of Levi's argument construction showed that what he was proposing and how he was justifying were related to what he knew about argumentation. His knowledge about what "good evidence" is and how to find or generate it (i.e., declarative and procedural McK-A) was involved in his argument construction. Regarding these McK-A, according to what he shared during the SRI, it was also related to the teacher's instructional supports, either directly (e.g., "Ms. Bowen gave [him] the tip," so he knew he could generate evidence through using his logic and he did so) or indirectly (e.g., he knew evidence should be valid and relevant, because he knew there would be an audience at his presentation and he needed to persuade his audience, which were the characteristics and requirements of this learning project designed by the teacher).

The next example presented in this part is David's argument construction. In this example, how David's knowledge about "good evidence" and justification were involved in his argument construction is described, as well as how he related his knowledge to the teacher's scaffolds. Through comparing David's argument construction with Levi's, it was found that students had different McK-A about "good evidence" and ways of finding evidence.

Example #05: David's argument construction

David also presented his design to the whole class at their presentation day. Table 5.2-1 below shows David's argument, which is the transcript he wrote for his presentation. David's claim was "NASA should buy my technology: The Europa rover" (Line #01). He supported his claim by justifying why NASA should consider exploring Europa (Line #05) and how his technology could help achieve the exploration of Europa (Line #03, #04).

Table 5.2-1 *David's argument for his NASA technology design project*

Line #	**David's Argument** (Students' writing, 2018/04/13)	**Analysis Notes** (i.e., My Interpretation)
01	My topic is the Europa Rover, and NASA should buy my technology: The Europa rover.	Claim making
02	My presentation has three parts: the technology, reasons to buy, and the exploration of Europa, to explain why NASA should buy my technology for the future space exploration.	
03	The technology: My rover [showing the blueprint of his rover drawn with Google Drawings] comes with built in laser drill, 360 wheels that are hovering under the rover. To withstand Europa's harsh winds my rover has a countermeasure. When the wind gets to a high enough level, the rover deploys four hooked steel ropes that bury themselves in the ice on the moon, then the 360 wheels attach electromagnetically to the bottom of the rover.	Evidence-based defending

04	How to get to the Europa: The rocket that carries my rover is called "White Bull" it is powered with antimatter fuel and made partly out of carbon nanotubes. The rover is called E.R.W.B. (Europa. Rover. White. Bull). The material . . .	Evidence-based defending
05	Why Europa? Europa is one of the most promising places for human development in the entire solar system. It has a sustainable water sources, and an okay environmental status. Like Earth, Europa has a rocky mantle and an iron core. The sustainable water source is an ocean that is under a layer of ice, 15 to 25 kilometres thick.	Evidence-based defending

During the SRI, David's argument was brought back to him to stimulate him to recall his thinking process of argument construction. Part of the transcript of the SRI is shown below in Table 5.2-2, as well as the researcher's analysis notes.

Table 5.2-2 *David's self-reported thinking process of developing his argument*

Line #	**Transcript of SRI with David** (Interview transcript, 2018/05/04)	**Analysis Notes** (i.e., My Interpretation)
	Researcher: . . . Can you share with me your thinking process of developing your presentation? . . . What was your thinking process about developing your presentation in that way, with that particular structure?	
06	I thought about those [the structure of his presentation including 3 parts] before I made it. This [the structure] sounds, and looks, and basically just is better . . .	Indicator of *metacognitive monitoring* [consciously keeping track of his own thinking process]
07	. . . I planned it out . . . so it makes sense to other people . . . I put why Europa here, kind of like a hook . . . Oh! Europa, we have not been there before, that is the exploration, that is cool! So, I put it here to get them interested.	Indicator of *procedural McK-A* [knowing how to make the justification make sense to and interest other people]
08	I was focusing on getting and giving more information, like more reasons and evidence, because, you know giving enough stuff is very important . . . I had various kinds of stuff, like words and pictures,	Indicator of *procedural McK-A* [knowing how to justify better, through providing sufficient evidence]

	we do not have to have pictures, but pictures help, help to explain . . . I was trying to make it more interesting, not boring to the other people . . . I used PowerPoint slides . . . you can put all you have [into the slides, such as] text, picture, and gifs . . .	Indicator of *procedural McK-A* [knowing how to justify better, through providing evidence in various formats]
09	But don't just do a Google search and use the first picture, maybe try to read a little bit. Like I used the picture of Europa, when I searched the picture of Europa, there were lots of Jupiter, the first one is Jupiter actually,	Indicator of *procedural McK-A* [knowing how to find relevant evidence]
10	I cannot use the picture of Jupiter when I was talking about Europa . . .You like to use something really about your topic.	Indicator of *declarative McK-A* [knowing what "good evidence" is: "good evidence" needs to be relevant]
11	And I also tried to get and use good resources and stuff as my evidence. Don't use a book from 1960, then it probably won't be as reliable as my 2018 book . . . So, for this project, I really like NASA website and other space agency websites. You know they're usually new and very good, 'cause they are kind of international, not supposed to lie or anything . . .	Indicator of *declarative McK-A* [knowing what "good evidence" is: "good evidence" needs to be current] Indicator of *procedural McK-A* [knowing how to find current evidence]
12	Good evidence is the thing, reliable, relevant, and current.	Indicator of *declarative McK-A* [knowing what "good evidence" is]

During the SRI, David shared his knowledge about what "good evidence" is (i.e., declarative McK-A) and the strategies he employed to find "good evidence" (i.e., procedural McK-A). David knew that "good evidence" needed to be not only "reliable [and] relevant," but also "current" (Line #12). To find relevant evidence, he knew that when he searched for pictures, he couldn't "just do a Google search and use the first picture." Instead he needed to read closely to make sure the picture was about and related to his topic (Line #09). To make sure the evidence was reliable and timely, he deliberately checked the publication date of the book and used information from websites that were updated regularly (Line #11). For this NASA technology design project, he preferred NASA's website and thought it was a reliable and timely source for evidence, because he thought it was an “international [organization] and not supposed to lie” (Line #11).

In addition to his knowledge about “good evidence,” David’s knowledge about justification was also involved in his argument construction. As he said, he knew how to organize the information and evidence to make sense to and interest other people, and he did so (i.e., procedural McK-A). He particularly planned the structure of his presentation and designed a “hook” to interest the audience (Line #07). Moreover, to better justify his claim, David knew he had better use sufficient evidence and in various formats (i.e., procedural McK-A). Thus, he “was focusing on getting and giving more information . . . more reasons and evidence” and “was trying to make it more interesting, not boring to the other people” “[with] various kinds of stuff, like words and pictures” (Line #08).

Comparing David’s McK-A with Levi’s, it was found that they had different knowledge about what “good evidence” is. David thought that, besides being valid and relevant (i.e., Levi’s idea), “good evidence” also needed to be timely and current. In addition, their procedural McK-A about how to find “good evidence” was also different. For example, Levi used his logic to generate relevant evidence from his inference, while David had his own examining strategies to ensure the relevance of his evidence (i.e., examining whether the picture recommended by the online search engine was about his topic).

During the semistructured interviews, which took place at the end of the data collection period, students were invited to share their experiences and thoughts around certain topics. The teacher’s scaffolding was one of these topics. During the interview, David also shared how he thought he knew his knowledge about argumentation. When I asked him “How do you think about Ms. Bowen’s questions about your thinking?” David shared with me:

> David: . . . yes, she always questioned and showed us how to think, and I think it was helpful . . . we never did that before . . . Like, *we all think how to be persuasive, but . . . we do our own work in different ways.* We had different topics, mine is the rover exploring Europa, someone, like Kelvin is working on smoothies, our topics are so different. Though, some of ours were similar, but still different. So, like, *we think in the same way to persuade NASA to buy the technology* . . . but Kelvin might be, like, do his research on nutrition, like vitamins and flavors, he also asked Adam to ask his father for suggestions, you know Adam's father is a doctor . . . but my research is mainly around space materials and powers . . . I cannot make mine by researching on nutrition . . . like, *we were not told what we should do, we just know what to do . . . with the purpose to persuade NASA to buy our technologies . . .*
> (Semistructured interview transcript, 2018/06/18)

What David shared provides some information that is helpful to understand why students, like Levi and David, had different McK-A, especially procedural McK-A about how to find the evidence they needed and how to justify. As David shared, with Ms. Bowen's scaffolds such as questioning and prompting on their *thinking*, they knew the goal of their argument construction, as well as how to *think* to achieve the goal, which was "to persuade." Knowing how to *think*, "[they] just know what to *do*" and how to *do*. Moreover, David also expressed that, because "[they] had different topics," they needed to use different ways to find the evidence they needed. For example, as David shared, Kelvin's topic was smoothies for the astronauts, thus Kelvin could find his supportive evidence "by researching on nutrition," which would not work for David's topic, which was a rover. In this way, even if the teacher, as discussed in the beginning of the section, did not confirm or teach students *the* way to find and search evidence, her scaffolds around the goal of this project and how to *think* to achieve the goal might help some students be aware of and apply their diverse McK-A during the process of their argument construction.

Students had a peer-assessment after their presentations. In that peer-assessment, Ms. Bowen asked them to choose two presentations they thought were "very convincing and well developed" (classroom recording transcript, 2018/04/13). Both Levi's and David's presentations were mentioned frequently as “very convincing and well developed” arguments. In what follows, I present another example: Jeff’s argument construction. Jeff’s argument was not chosen by any of his classmates as “very convincing and well developed,” and one of his classmates commented that “[Jeff’s argument] lacks necessary evidence and information to be persuasive” (classroom recording transcript, 2018/04/13). However, this example shows that Jeff’s McK-A was also involved.

Example #06: Jeff’s argument construction

Jeff also presented his design to the whole class. Jeff’s full transcript for his presentation, which was also the final version of his argument, is shown below in Table 5.3-1.

Table 5.3-1 *Jeff’s argument for his NASA technology design project*

Line #	**Jeff’s Argument** (Students’ writing, 2018/04/13)	**Analysis Notes** (i.e., My Interpretation)
01	Hello, my name is Jeff, and my space technology is a Shark Ship. NASA should buy this ship.	Claim making
02	The ship is made to go to Uranus because NASA has never been on Uranus, that is why my technology is so important because, no one has been on Uranus.	Evidence-based defending
03	It will help advance our knowledge by going to Uranus and actually seeing the evidence that got scanned with human eyes. And that’s the benefit of my technology.	Evidence-based defending

Jeff did not participate in an SRI, but I had a chance to do an informal interview with him in class before his presentation. During the interview, he told me, “I had a blueprint, too, like showing the different parts . . . and functions [of each part] . . . [but] I deleted it. . . .” When I asked him why he decided to delete that part, he replied:

> Jeff: . . . that [the blueprint] is not evidence . . . even if it is evidence, I do not need that much . . . too much is always not good . . . mine, like, the “never been to Uranus” part and the “advance our knowledge,” it is enough and just convincing . . .
> (In-class informal interview transcript, 2018/04/13)

As Jeff shared, he thought the blueprint showing details of his design was “not evidence” and that “too much [evidence] is always not good,” thus he deleted his blueprint and details about his “shark ship” from his argument. This decision might to some extent have resulted in, as one of his classmates commented, his final argument “lack[ing] necessary evidence and information to be persuasive.” In this way, Jeff’s McK-A (i.e., McK-A about what evidence is and how to justify with evidence) was also involved in his argument construction and influenced his decision making during the process.

This section has described how students constructed their arguments, with their Mc-A being involved in the process. It was discerned that students’ McK-A and *metacognitive control* were related to their decision making regarding how they would think and do while they were engaged in argument construction. Data analysis also revealed that students’ McK-A had similarities as well as individual differences. Students attributed their McK-A (both the similar and the diverse parts) to the teacher’s instructional supports. According to what students shared, (1) with the teacher’s scaffolds, students knew that the goal of their argument construction was “to persuade” (conditional McK-A); (2) with the teacher’s further scaffolds, students knew that they needed evidence to persuade, that is, they knew the necessity and importance of evidence (declarative McK-A); (3) the teacher suggested and modelled a way of thinking to frame their claims, and students took that suggestion and adjusted their way of thinking (metacognitive control); (4) taking their unique topics into consideration, students further knew what evidence was “good” for their own topics as well as how to find the “good evidence” they needed ([diverse] declarative and procedural McK-A); and finally (5) they supported their various claims with their own evidence in different ways.

5.2 Argumentative Dialogues During the First Focused Activity

As described in Chapter 4, there was a Q&A after each student's presentation. Students would take and answer some questions from their audience after their presentations, both the presentations to the whole class and the ones within small groups. The Q&A had both a pedagogical purpose as, using Ms. Bowen's words, "Q&A is . . . a kind of communication between students, they communicate with each other and learn from each other" (conversation with the teacher, 2018/03/16), and a research purpose as it would engage students in argumentative dialogues, which is one of the research focuses of this study. Thus, the majority of students' argumentative dialogues discerned in the first focused activity took place during the Q&A. In addition, as described previously, while students were constructing their arguments, students in groups shared their work and feedback. It was found that during this small-group sharing, argumentative dialogues also took place.

When I analyzed students' argumentative dialogues, I found that these dialogues could be distinguished into two kinds. The first is argumentative dialogues about scientific topics (e.g., students' designed technologies). In this kind of dialogue, students discussed their different ideas about certain scientific topics around sky science, such as whether a spaceship can travel at the speed of light or possible ways for deep space communication. The other type is argumentative dialogues about argumentation itself. In this kind of dialogue, students discussed their different ideas about argumentation (e.g., evidence, claim, argument and reasoning). For example, students discussed different strategies for finding valid evidence and different criteria for being relevant. Kuhn et al. (2013) termed this kind of dialogue or talk—that is, "talk about the discourse, distinguished from talk about the topic"—as "metatalk" (p. 456). In this study, metatalks between or among students were also discerned. (I also adopt this term "metatalk" to refer to students' argumentative dialogues about argumentation.)

How students' Mc-A was involved and manifested within these two kinds of argumentative dialogues were different. Therefore, in this section, I describe students' Mc-A in these two kinds of argumentative dialogues separately.

5.2.1 Argumentative Dialogues about Scientific Topics

Students' argumentative dialogues about scientific topics took place during both the Q&A and their small-group sharing. Examinations of relevant data revealed that, similar to the aforementioned argument construction, students' knowledge aspect (McK-A) and regulation aspect (McR-A) of metacognition were present in their argumentative dialogues. Likewise, students tended to relate and attribute their Mc-A to the teacher's instructional scaffolds. When students were engaged in argumentative dialogues, their *metacognitive monitoring* manifested and was related to the teacher's scaffolds. Thus, before I describe how students engaged in argumentative dialogues with their Mc-A and how they perceived their Mc-A, I first give a brief summary about the teacher's scaffolds around *metacognitive monitoring.*

In addition to the aforementioned scaffolds around McK-A and *metacognitive control*, during this NASA technology design project, the teacher also provided some scaffolds about *metacognitive monitoring*. Within the teacher-led whole-class discussion about the importance of evidence (science class on 2018/03/21; see Appendix D-3 for full transcript), Ms. Bowen encouraged students to ask themselves "Will this make sense to other people?" and "Does this make sense to me?" while they were preparing their own arguments and listening to others. Then, through *modelling thinking*, Ms. Bowen further shared with students her thinking process of developing her own argument:

> Ms. Bowen: . . . if I am doing my pitch . . . I will . . . think questions like “Is my argument convincing?”, “Does it make sense to other people, my evidence and my explanation?” all the time . . . that is my way of thinking of preparing my pitch . . . (science class on 2018/03/21; see Appendix D-3 for full transcript).

Similar scaffolds were continually provided in subsequent classes (i.e., science classes on 2018/04/04 and 2018/04/06) as the teacher kept reminding and encouraging students to keep these questions (e.g., “Is my evidence convincing?” and “Will this make sense to other people?”) in their minds and question themselves while they were working on their projects.

Before students’ presentations on the presentation day (2018/04/13), the teacher opened a whole-class discussion (see Appendix D-5 for full transcript). The teacher and students discussed again how to monitor their comprehension of others’ presentations to raise helpful questions and give constructive feedback to each other. The teacher first asked students to think about “How can we ask good questions . . .?” and “What could be the thinking process of asking a good question?” Then, building on students’ ideas that they “need to focus [on]” and “pay attention [to]” what other people were talking about, Ms. Bowen shared her own thinking process with students and showed how she would monitor her own thinking and comprehension while listening to the students’presentations:

> Ms. Bowen: . . . later, when you present your technology, I will think “Do I understand his words?” . . . I will pay more attention on the part whether your evidence is supporting your claim . . . try to monitor whether you are understanding or not. Asking ourselves, “Do I understand?” “What is the evidence?” “Is the evidence supporting?” . . . (Classroom recording transcript, 2018/04/13; also shown in Appendix D-5)

With this *modelling thinking* scaffold, Ms. Bowen showed her students how she would ask herself questions such as “Do I understand?” to monitor her comprehension while she was listening to others’ presentations. After this discussion, students started their presentations.

Thus far, I have briefly described the teacher’s scaffolds around *metacognitive monitoring*. In what follows, with two illustrating examples, which were from the Q&A and small-group sharing respectively, I explain how students engaged in argumentative dialogues with their Mc-A being involved and how they attributed their Mc-A to the teacher's scaffolds.

The first example is from students' Q&A. During the Q&A, students were encouraged to ask and answer questions. Therefore, different ideas around certain scientific topics frequently emerged. In this way, the dialogical form of argumentation took place. Through these argumentative dialogues, some students changed their initial ideas about certain scientific topics and accepted new ones. In the following examples, I describe how students participated in argumentative dialogues with their Mc-A, and why and how students changed and were willing to change their initial ideas.

Example #07: Argumentative dialogue between Henry and Nate

Henry's design was a space sports centre. After his presentation, through questions and answers, an argumentative dialogue took place between Henry and Nate (shown below in Table 5.4-1). In this short conversation, Nate asked Henry how Henry would "send off [his] space centre into space?" (Turn #01). Then, they exchanged their ideas about how they would power their rockets. Finally, with Nate's evidence (i.e., both evidence-based rejecting [Line #03] and evidence-based defending [Line #05]), Henry said he "will consider [Nate's suggestion]" (Line #06). Actually, Henry took Nate's suggestions eventually, as he added "a fuel part into [his] assignment" that he submitted to the teacher (SRI transcript, 2018/06/18). In other words, Henry changed his initial idea about how to power his rocket and accepted Nate's idea, which was a new one to him.

Table 5.4-1 *Argumentative dialogue between Henry and Nate*

Turn #		**Argumentative dialogue (Nate & Henry)** (Classroom recording transcript, 2018/04/13)	**Analysis Notes** (i.e., My Interpretation)
01	Nate:	What kind of fuel or energy are you going to use to send off your space centre into space?	Question emerged

02	Henry:	I will use gases, just like the gas the cars use.	Claim making
03	Nate:	You know that gas is not the most efficient fuel. You will need a lot of gas, and it will generate lots of carbon dioxide.	Evidence-based rejection
04	Henry:	[nodding along to Nate's words (the "carbon dioxide" part)]	Showing agreement
05	Nate:	I use antimatter as the power for my rocket. That is more efficient and cleaner than gas.	Evidence-based defending
06	Henry:	Yes, I think I will consider about it.	(possible) Consensus

This episode was brought back and shown to both Nate and Henry in the SRIs with them. After viewing this episode, they were invited to share what and how they were thinking at that time. Parts of the transcripts of their SRIs are presented in Table 5.4-2 and Table 5.4-3.

Table 5.4-2 *Nate's self-reported thinking process regarding the argumentation with Henry*

Line #	**Transcript of SRI with Nate** (Interview transcript, 2018/05/04)	**Analysis Notes** (i.e., My Interpretation)
	Q: What were you thinking when you asked Henry that question?	
07	I was thinking, okay, this is going to happen, then, but, how, I was thinking the how, how exactly is this going to happen? I was thinking he might forget to put certain information to explain.	Indicator of *metacognitive monitoring* [monitoring his comprehension (i.e., he knew he was not convinced because the evidence/information was not enough)] Indicator of *declarative McK-A* [knowing the necessity and importance of evidence]
08	We need enough information to persuade . . .	Indicator of *procedural McK-A* [knowing how to justify and how to persuade] Indicator of *declarative McK-A* [knowing the necessity and importance of evidence]
09	I did research on fuel, like, my rocket and robot also need fuel, I use the antimatter and David also uses it . . . Yeah, I think I know fuel well	Indicator of *metacognitive monitoring* [monitoring and being aware of his own thinking]
10	. . . so, I asked that question . . .	

As Nate shared (see above in Table 5.4-2), he asked that question because he knew he was not convinced, because Henry had not provided sufficient evidence (Line #07, #08). With these words, Nate's metacognitive monitoring (i.e., monitoring his thinking and being aware that he was not convinced) and McK-A about the necessity of evidence were manifested. He demonstrated that his Mc-A, both the knowledge and regulation aspects, was involved when he was engaged in this argumentative dialogue with Henry and it affected his performance, such as raising the question (Line #01, #10) and providing his evidence (Line #03, #05).

From Henry's perspective (see below in Table 5.4-3), through monitoring his comprehension he knew that Nate's "ideas was good and made sense to [him]" (Line #11). In addition, he knew that Nate's suggestion was based on his (Nate's) research and research was a reliable source for evidence (i.e., declarative McK-A about evidence) (Line #12). Moreover, he was aware that "more evidence is . . . good for [his] work" (Line #14). Thus, with all this McK-A and metacognitive monitoring involved, he decided to accept Nate's idea and included it in his project as another piece of evidence to support his claim.

Table 5.4-3 *Henry's self-reported thinking process regarding the argumentation with Nate*

Line #	**Transcript of SRI with Henry** (Interview transcript, 2018/06/18)	**Analysis Notes** (i.e., My Interpretation)
	Q: What were you thinking when Nate asked you that question about the fuel?	
11	. . . His idea was good, made sense to me, I think it is better than gas,	Indicator of *metacognitive monitoring* [monitoring his comprehension through examining whether other's words made sense to him or not]
12	and I knew that is from his research . . . research is always good evidence,	Indicator of *declarative McK-A* [knowing what "good evidence" is and research is a "good" source of evidence]
13	so, I agreed to take it,	he changed his initial idea
14	and you know, more evidence is always good for	Indicator of *declarative McK-A* [knowing

	my work . . . it was good to know something new, like my knowledge was expanded . . .	the sufficiency of evidence is important or helpful]

This example, from both Nate's and Henry's perspectives, illustrates how students participated in argumentative dialogue with their Mc-A, both knowledge (McK-A) and regulation aspects (McR-A, particularly the metacognitive monitoring). Being aware of the importance of evidence, students examined the evidence to decide whether they would change their ideas. Through monitoring their comprehension of their peers' evidence, they would know whether the evidence made sense to them and whether they were convinced. With convincing evidence, students would and were willing to change their initial ideas and accept new ones. In this way, McK-A and metacognitive monitoring were involved in the process of changing ideas.

The second example below is from students' small-group sharing during their argument construction. While they were sharing their own work and giving each other feedback, argumentative dialogues took place. This example shows how students' Mc-A was involved while they were participating in argumentative dialogue and how their Mc-A was related to the changes in their ideas. In addition, within this example, students shared how they thought the teacher's scaffolds influenced their Mc-A.

Example #08: Argumentative dialogue among Levi, Nate, David, and Jayraj

Levi, Nate, David, and Jayraj were grouped together to share their work and get feedback from the teacher and each other to further develop their arguments (see Appendix D-4 for the full transcript). After Ms. Bowen asked Nate "What do you want from us?", Nate replied that he wanted some ideas about space communication. While other students were trying to give him suggestions, different ideas appeared around whether the X-ray or other radio waves that we use to communicate with on Earth would be a good option for Nate's space communication.

Argumentative dialogue around possible methods of space communication took place (Table 5.5-1).

Table 5.5-1 *Argumentative dialogue among Nate, David, Levi, and Jayraj*

Turn #		**Argumentative Dialogue** (Classroom recording transcript, 2018/04/09)	**Analysis Notes** (i.e., My Interpretation)
01	Nate:	. . . I want to know how my robots on other planets can communicate with the Earth . . .	
02	Levi:	You can use, maybe, X-ray.	
03	Jayraj:	Yes, X-ray, or like radio waves.	
04	Nate:	Yeah, but, like, it [using X-ray or radio waves] will take a long time.	Claim making
05	David:	Yes, it will take decades to get there.	Simple supporting
06	Levi:	No, it will not. When I send an email, almost literally across the world, it gets there in a couple seconds.	Counter-claim making Evidence-based defending
07	David:	No, it does not.	Simple rejecting
08	Jayraj:	Yes, it does for me. I had exactly the same [experience].	Evidence-based supporting
09	Nate:	That [sending and receiving emails in seconds] is because there are satellites to receive and transfer your information, but there is no satellite in space.	Evidence-based rejecting
10	Jayraj:	Really?	Simply challenging
11	David:	Yes, exactly.	Simple supporting
12	Nate:	Yes, I did my research on this, so I want to know whether you have any good ideas.	
13	Jayraj:	Oh. [nodding]	Consensus achieved
14	Levi:	Oh, yes. Then you might want to distinguish whether the information you want to send back to Earth is emergency or not.	Consensus achieved; students gave further suggestions
15	Nate:	[nodding]	

Regarding this question (i.e., whether the X-ray or other radio waves that we use to communicate on Earth would be a good option for Nate's space communication), Levi and Jayraj thought it was feasible (Turn #02, #03, #06), while Nate and David insisted that it was not a good method because they thought it would take a very long time to communicate with either X-ray or other radio waves (Turn #04, #05). Then, Levi provided his evidence, citing his experience of sending and receiving emails "across the world . . . in a couple seconds" (Turn #06). Next, Nate rejected Levi's evidence, pointing out the difference between space communication and communication on Earth by saying that "there are satellites to receive and transfer your information, but there is no satellite in space" (Turn #09). Jayraj simply challenged Nate's evidence, asking "Really?" (Line #10). After Nate explained that his evidence was from his research, Jayraj and Levi agreed with him and changed their previous idea (i.e., that using X-ray or other radio waves was a good choice for space communication), accepting the new one (i.e., that using X-ray or other radio waves was not a good choice for space communication because it would take a long time) (Line #13, #14).

I was eager to know students' thinking processes of participating in this argumentative dialogue, especially why and how Levi and Jayraj decided to change their ideas, so I brought this episode from the classroom recordings back and showed it to them during the SRIs. Within these interviews, students demonstrated how their Mc-A had been involved in this argumentative dialogue and also shared how they perceived their Mc-A. Transcripts of the SRIs with Levi and Jayraj are shown below in Table 5.5-2 and Table 5.5-3.

Table 5.5-2 *Levi's self-reported thinking process regarding their argumentative dialogue*

Line #	**Transcript of SRI with Levi** (Interview transcript, 2018/05/04)	**Analysis Notes** (i.e., My Interpretation)
	Q: What were you thinking when you were giving Nate your suggestion? And how did you know it, the X-ray might work?	
16	When I heard the question . . . I thought it was a very simple question with clear and easy	Sharing his thinking process when he heard the question

	answers. I thought the X-ray might work . . . I don't know how I knew it, just an idea come up to my mind.	
	Q: What were you thinking when you heard Nate and David saying that it would take a long time?	
17	. . . without his [Nate's] further, his later explanation and evidence, at that time, the idea that "it will take a long time" did not make much sense to me.	Indicator of *metacognitive monitoring* [monitoring his comprehension and examining whether his classmate's words made sense to him]
18	You know, you need evidence . . . and I was providing my evidence . . . I thought it was good evidence, you know everyone has the experience . . .	Indicator of *declarative McK-A* [knowing the necessity and importance of evidence] (possible) Indicator of *declarative McK-A* [knowing what "good evidence" is]
19	His [Nate's] evidence is convincing, actually, furthered my thinking, you know, I just thought the communication on Earth, and it was totally different from the deep space . . .	Indicator of *metacognitive monitoring* [monitoring his comprehension, knowing he was convinced and his thinking was "furthered"] Reflecting on his own thinking process
	Q: So, you agreed with him, right? Why?	
20	Yeah, I agreed with him	Deciding to change his initial idea and accept the new idea
21	because of the evidence, his evidence was good . . . you know, doing research is always a good way to find quality evidence.	Explaining why he changed his idea Indicator of *declarative McK-A* [knowing the importance of evidence] Indicator of *procedural McK-A* [knowing how to find "good evidence"]

According to what Levi shared during the SRI, when he heard Nate's idea/claim that "[using X-ray or radio waves] will take a long time" (Line #04) without supportive evidence, he (Levi) knew that the idea did not make sense to him, thus he was not convinced (Line #17). This (i.e., Line #17) was taken as an indicator of his metacognitive monitoring, because he demonstrated that, at that moment, he examined his comprehension of Nate's idea and knew he was not convinced. Then, after Nate provided his evidence (Line #09), Levi realized that "his [Nate's] evidence [was] convincing" to him and "furthered [his] thinking" (i.e., metacognitive monitoring), thus he was convinced (Line #19). Knowing the importance of evidence (i.e., McK-A about evidence; Line #18) and being aware that he was convinced by Nate's evidence (i.e., metacognitive monitoring), Levi decided and was willing to update his initial idea. This is the process of how Levi changed his idea, in which his McK-A about evidence and metacognitive monitoring was involved.

When I noticed the indicators of Levi's metacognitive monitoring, I further asked some follow-up questions to probe how he knew it (i.e., metacognitive monitoring). We had the following conversation during the interview:

> Researcher: You said you knew whether you were convinced or not. How do you know it, if you are convinced or not?
>
> Levi: How I know it . . . I just know it . . . like, you asked "Is this convincing?", "Does this really make sense?", "Is this the real situation?", like, there is no satellite in space, is this the real situation? It is [the real situation], then, it is convincing.
>
> Researcher: You mean you were using the self-questioning strategy, right?
>
> Levi: Yes . . . you ask yourself questions . . .
>
> Researcher: Then, how do you know this strategy, like asking yourself these questions?
>
> Levi: I think, I remember we talked about it in class . . . Ms. Bowen . . . told us we can ask . . .
>
> (SRI transcript, 2018/05/04)

Levi's words confirmed that he consciously monitored his comprehension while he was engaged in the argumentative dialogue with his peers. Moreover, according to what he said, he knew the self-questioning strategy to monitor his thinking and comprehension because "[they] talked about it in class" and "Ms. Bowen told [them]." In other words, Levi attributed his metacognitive monitoring, knowing and applying the strategy for monitoring his comprehension, to the teacher's scaffolds.

Within this argumentative dialogue (shown above in Table 5.5-1), Jayraj also changed his idea and accepted a new one that he had not known before. During the SRI with him, Jayraj also shared how he was thinking while he was engaged in that dialogical form of argumentation, as well as why and how he changed his idea (see below in Table 5.5-3).

Table 5.5-3 *Jayraj's self-reported thinking process regarding their argumentative dialogue*

Line #	**Transcript of SRI with Jayraj** (Interview transcript, 2018/05/04)	**Analysis Notes** (i.e., My Interpretation)
	Q: What were you thinking when you were giving Nate your suggestion? And how did you know it, the X-ray might work?	
22	I did not really think too much, I mean, when I heard his question, I was trying to think the communication on the earth, like, phone call, internet, so I agreed with Levi, just use the way we communicate every day, I thought.	Reflecting on his own thinking process (possible) Indicator of *metacognitive monitoring* [keeping track of his own thinking process]
23	Levi's evidence was exactly what I was thinking . . .	Indicator of *metacognitive monitoring* [keeping track of his own thinking process and/or monitoring his comprehension]
	Q: What were you thinking when you heard Nate at this moment [Nate was sharing with them what he knew based on his research Turn #09]?	
24	. . . It was my first time I heard about this [Nate's evidence], so I was not very sure what he said was correct.	Explaining why he changed his idea Indicator of *metacognitive monitoring* [monitoring his comprehension (i.e., he was not convinced)] Indicator of *declarative McK-A* [knowing evidence needs to be valid]
25	But after he told me it was from his research, I believed it,	Explaining why he changed his idea Indicator of *procedural McK-A* [knowing research is a good way to gather valid evidence] Indicator of *metacognitive monitoring* [monitoring his comprehension (i.e., he was

		convinced)]
26	I mean, I accepted his evidence and agreed,	Deciding to change his initial idea and accept the new idea
27	and you know, it is Nate . . . yeah, I knew him, he would not be lying . . .	Explaining another reason why he changed his idea

For Jayraj, he knew that "it was [his] first time [he] heard about [Nate's evidence], so [he] was not very sure what [Nate] said was correct" (Line #24). That is, through monitoring his comprehension, he knew that he was not convinced because he was not sure whether Nate's evidence was valid or not. When Nate told him that it was from his (Nate's) research, Jayraj decided to accept Nate's evidence as valid because he knew research was a reliable source for evidence and Nate was a reliable person who "would not be lying" (Line #25, #26, #27, and Turn #13). Then, after making sure that Nate's evidence was valid, Jayraj decided to agree with him, accepting Nate's idea, which was new to him. In this way, the SRI with Jayraj demonstrates that his metacognitive monitoring and McK-A were also involved while he was engaged in this argumentative dialogue and updating his scientific knowledge about space communication.

In the semistructured interview, Jayraj shared that he appreciated Ms. Bowen's scaffolding around metacognitive monitoring. According to what he said, because he responded positively to the teacher's scaffolds (i.e., he "took [the teacher's suggestion]," Jayraj managed to monitor his comprehension while listening to others:

> Jayraj: I really love that . . . she [Ms. Bowen] told us how to be a good audience . . . to think "Do I understand this?" "Does this make sense to me?" . . . I took that, and I found it was useful. You know what you should think [while other people are talking], so won't get distracted . . .
> (Interview transcript, 2018/06/18)

According to Jayraj's self-report interview, it was because Ms. Bowen provided metacognitive scaffolds showing them "what [they] should think" while they were listening to other people that

Jayraj learned metacognitive monitoring. He “took that” (i.e., accepted and followed the teacher’s scaffolds) and found those scaffolds “[were] useful.” Following the teacher’s suggestion, Jayraj monitored his thinking and comprehension considering whether he understood what his peers were talking about through asking himself questions. In this way, Jayraj demonstrated his metacognitive monitoring retrospectively during the semistructured interview and elaborated how his metacognitive monitoring was affected by the teacher’s scaffolds.

In sum, with these two examples, it can be suggested that (1) students argumentative dialogues took place during the Q&A, which was designed to engage students in argumentation, and small-group sharing; (2) during these argumentative dialogues, some students refined their scientific knowledge as they changed and were willing to change their ideas through examining evidence; (3) students’ Mc-A was present while they were participating in the argumentative dialogue, especially their metacognitive monitoring, which played an important role in changing their ideas; and (4) students attributed their metacognitive monitoring to the teacher’s instructional supports.

5.2.2 Argumentative Dialogues about Argumentation Itself

As described previously, sometimes students had different metacognitive knowledge during argumentation. For example, as shown in example #05 and example #06, regarding what “good evidence” is and how to find it, Levi and David held different ideas. However, without chances to share their thoughts, students might not know that their McK-A is different from each other. The designed Q&A that followed each presentation provided students opportunities to share and discuss their ideas. With these opportunities, students could realize that they had different ideas, not only about certain scientific topics, but also about argumentation. Thus, during the Q&A, students’ argumentative dialogues about argumentation were also discerned. In these dialogues students discussed their different ideas about argumentation, such as what they thought were good strategies to find valid evidence. It was found that these metatalks, as a form of social interaction, had the potential to influence students' Mc-A. Next I present an example that includes both an excerpt from classroom conversation and the corresponding interviews. This example shows how the metatalk could affect students' Mc-A, especially McK-A. In addition, this example also illustrates that the teacher's instructional support played an important role.

Example #09: Metatalk between Nate and Levi

In Levi's presentation, which was described in detail previously in Table 5.1-1, he introduced to the whole class why his technology—Solitude 1, a rover exploring Triton—was a good design that NASA should approve and support. Before he explained the specific design of his rover, he talked about why human beings need to explore Triton and some benefits of the exploration as his supportive evidence. After his presentation, Nate challenged the relevance of Levi's evidence and they had the following conversation (shown in Table 5.6-1).

Table 5.6-1 *Argumentative dialogue between Levi and Nate*

Turn #		**Argumentative dialogue** (Classroom recording transcript, 2018/04/13)	**Analysis Notes** (i.e., My Interpretation)
01	Nate:	Why you talked . . . you should focus on the rover, but not how to pull the planet closer, that is totally a different topic. You should talk more about your topic, that is not related.	Challenging the relevance of evidence
02	Levi:	No, it is not [a different topic], I am just saying, if we research it, we could know more about it. If we want to pull it closer, we could see if there are dangerous chemicals, anything that we need to watch out for.	Defending the relevance of evidence
		Ms. Bowen: We have discussed that the Q&A is to help each other and make our work better and stronger . . . for these comments and suggestions,	The teacher's intervention: Reminding them the social norms of argumentation

		we do not take them personally . . . We should think about how we can help Levi to make his work better. Nate, can you please rephrase what you think can make Levi's work better?	
03	Nate:	. . . if you spent more time talking about your topic closely, it will make it stronger . . . because you talked a lot about, like pulling Triton closer to the earth, and like, the Voyager 2. These are not really related to the topic . . . It needs to be related, then, it is persuasive . . . like 99% [of the information] should be closely and directly about the topic . . . Otherwise, it is not good . . .	Challenging the relevance of evidence Indicator of *procedural McK-A* [knowing how to be convincing (with relevant evidence)] Indicator of *declarative McK-A* [knowing evidence needs to be relevant and what relevant evidence is]
04	Levi:	It is related, I talked all these, I said if we research we could know more, and my rover is to do the research. They are related to the topic . . . I reattach that part back to the system, so it is relevant . . .	Indicator of *declarative McK-A* [knowing evidence needs to be relevant and what relevant evidence is] (different from Nate's) Indicator of *procedural McK-A* [knowing how to be convincing (with relevant evidence)] (different from Nate's)

Nate asked Levi why he talked so much about information that was not related to his topic (Turn #01). Levi answered back, insisting that it was relevant and related to his topic (Turn #02). At that moment, Nate and Levi held opposite ideas and these ideas were about the way Levi developed his argument. In other words, Nate expressed his criticism of Levi's way of doing his (Levi's) project/assignment. Noticing this, Ms. Bowen intervened in their dialogue immediately through reminding both of them the social norms that they had discussed before their presentations (see Appendix D-5, Line #12 "[with Q&A] we are not criticizing . . . we are helping each other to improve our work . . ."). Ms. Bowen emphasized that "the Q&A is to help each other and make our work better and stronger" and reminded them not to "take [the comments or suggestions] personally" and then encouraged them to continue their conversation.

After the teacher's intervention, Nate elaborated why he thought Levi's evidence was not relevant (Turn #03). In this way, Nate expressed his McK-A about the relevance of evidence. Nate thought that most or all of the evidence should be "closely and directly about the topic," then, it was relevant; otherwise the evidence was not relevant and the argument would not be very strong (Turn #03). Then, while Levi was responding to Nate's idea, Levi's McK-A manifested too. Levi thought as long as he could "curve back" and "reattach" the evidence to the topic, then it was relevant, even if the evidence might be "a little bit off topic" (Turn #04). In this way, both of them expressed their own McK-A about the relevance of evidence within this metatalk, which were different from each other. Because the class time was limited and there were other students' presentations afterwards, their conversation stopped there.

To learn more about what and how Nate and Levi were thinking while they were engaged in this metatalk about the relevance of evidence, I brought this episode to the SRIs with them. During the SRIs, their thinking processes at the time and how they thought about their metatalk were further probed. Parts of the interview transcripts are shown below in Table 5.6-2 and Table 5.6-3.

During the interview (see below in Table 5.6-2), Levi shared that he appreciated Nate's questions and comments and thought they "were helpful" (Line #06). Moreover, Levi also shared that with the interactions with Nate, he further realized that, even if he could not have "all the evidence closely related to" the topic, adding more and explicit explanation of how the seemingly off-topic information connected to the claim would help (Line #08). And he did so, he revised his transcript, adding the explanation before he sent his assignment to the teacher. In other words, during that metatalk, Levi expressed what he thought about evidence (i.e., McK-A) and learned Nate's ideas. Their metatalk also brought changes to Levi's McK-A.

Table 5.6-2 *Levi's self-reported thinking process regarding the dialogue with Nate*

Line #	**Transcript of SRI with Levi** (Interview transcript, 2018/05/04)	**Analysis Notes** (i.e., My Interpretation)
	Q: . . . can you share with me what were you thinking during that conversation with Nate?	
05	I was thinking, yeah, we should definitely have information being relevant, while I mean they could go a little bit off topic, like I did, and then curve back, and reattach it to the system . . .	Indicator of *declarative McK-A* [knowing evidence needs to be relevant and what relevant evidence is] Indicator of *procedural McK-A* [knowing how to be convincing (with relevant evidence)]
06	. . . his comments were helpful . . . he asked me that question and I answered. I explained how I thought and how I organized all these . . .	Sharing how he thought about Nate's comments
07	. . . just like I said, there was not much information about Triton, so I needed to use my logic [to support my claim] . . . that's why it is very hard to make all the information closely relevant . . .	Indicator of *procedural McK-A* [knowing how to generate or find evidence he needed]
08	. . . with his question, I think, what I am thinking now is 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 connected . . . include that part, my answer to his question, in my presentation will be better . . . [when he submitted this assignment to the teacher, he revised his transcript adding that part.]	Indicator of (refined) *procedural McK-A* [knowing how to be convincing (with relevant evidence)]

Likewise, after the metatalk with Levi, Nate's McK-A was also refined (see below in Table 5.6-3). One interesting change was that the percentage he used to describe how much evidence or information should be "closely and directly related to the topic" decreased from 99% to 85–90% (Turn #03 and Line #11). Moreover, at the end of the interview, he expressed that some background information, which might be not closely related to the topic, was helpful (Line #12). That was different from his previously expressed McK-A that "most or all" of the information included should be directly about the topic (Turn #03). In this way, his McK-A had also been revised through this interaction with Levi.

Table 5.6-3 *Nate's self-reported thinking process regarding the dialogue with Levi*

Line #	**Transcript of SRI with Nate** (Interview transcript, 2018/05/04)	**Analysis Notes** (i.e., My Interpretation)
	Q: . . . can you share with me what were you thinking during that conversation with Levi?	
09	. . . like, I was thinking, he talked a lot about pulling Triton closer to the earth and the Voyager 2 . . . at that time, before he explained . . . I was thinking he should spend *most* [he stressed the word in italics] or all of his time talking about the rover . . . you need to talk about what you want to talk about, like, your technology, not other things . . .	Indicator of *procedural McK-A* [knowing how to be convincing (with relevant evidence)]
10	. . . after he explained, I can see the connection . . . he reattached back to his topic, but still, he talked too much about other things . . .	Sharing his thinking process
11	You should focus, maybe 85% to 90% . . . you can talk about other things, but only a little part, and he should also explain . . . how these are connected . . . some background information . . . [is] helpful . . . giving the audience the background, I am going to add some about the environment of the planet [my rockets are going to explore] . . .	Indicator of (refined) *procedural McK-A* [knowing how to be convincing (with relevant evidence)]

With this example, it can be suggested that (1) when students explicitly talked about their thinking process and argumentation itself, they demonstrated their Mc-A; (2) after their McK-A manifested within the metatalks, students could realize that they might have different McK-A, such as different metacognitive knowledge about relevant evidence; (3) the metatalk, as a form of social interaction, had the potential to bring changes to their existing McK-A; (4) the teacher's instructional supports were important. As shown in this example, it was the teacher's intervention that reminded students of the social norms of argumentation: they challenge each other to help each other improve their work and do not take others' comments personally, thus ensuring the metatalk could continue. These social norms, as the "unwritten rules" (Lemke, 1990), are important for the emergence and development of students' argumentation (Kelly, 2008).

After all the students presented their arguments (i.e., the technologies they designed for NASA's future space exploration), the first focused activity and the first learning unit ended. Then, they moved to the second and third learning units, which were Air & Aerodynamics and Flight. In the middle of the second learning unit, the second focused activity, which was an argument evaluation task, was implemented. In the next section, I describe how students engaged in argument evaluation, emphasizing how their Mc-A was involved in the process.

5.3 Argument Evaluation in the Second Focused Activity

In this section, I describe how students conducted and completed an argument evaluation task which was designed as an individual task. Analysis of the relevant data not only revealed that students' Mc-A was involved in the process of argument evaluation, but also suggested that students' actual thinking processes of argument evaluation might be more complex than what can be represented in their written answers.

After students learned the properties of air, they were invited to complete an argument evaluation task (refer back to Chapter 4). This task had two parts. In the first part (refer back to Figure 4.3), students were asked to choose the most convincing argument from four that were trying to answer the question "Which soccer ball is heavier, the inflated one or the flat one?" These four arguments had different claims and corresponding evidence. In the second part (refer back to Figure 4.4), students were asked to decide which one was more convincing between two arguments making the same claim (i.e., the inflated soccer ball is heavier than the flat one), but had different justifications and different evidence. In both parts, besides the choices, students were asked to explain the reasons for their decisions and their thinking processes of making their choices.

Students' written evaluation tasks were collected. All 18 students participated in this task. Two students did not write any further explanation of their choices, thus they were excluded from the analysis. The other 16 writings were reviewed and analyzed. Some of their writings were also brought to the SRIs to review and learn students' thinking processes during this task. Analyses of all these data revealed that students' Mc-A was involved in their argument evaluation. In what follows, how students performed the first part of the argument evaluation task and how their performances were related to their Mc-A during the process is described, followed by the second part of the argument evaluation.

5.3.1 Evaluating Arguments with Different Claims

Regarding the first part of the task, I first describe the patterns that emerged from analyzing the students' written answers in the worksheets (16 in total), particularly their answers to the question "Which argument is the most convincing one? And why?" Then, students' self-reported thinking processes were analyzed to further interpret how they evaluated arguments, especially how their Mc-A was involved in the process. These self-reported thinking processes included both what they wrote in the worksheet (i.e., their written answer describing the thinking process of how they made their choice) and what they shared in the SRIs.

When students were asked to choose the most convincing argument with different claims, their written responses demonstrated that all of them (16) agreed and shared the same viewpoint with the one they chose. In other words, even if they made different choices regarding the most convincing argument (11, 3, 0, and 2 students chose A, B, C, and D as the most convincing one, respectively), they tended to agree with the claims in the arguments they chose. For example, Ivan chose student B as making the most convincing argument, and agreed that "the flat [soccer ball] is heavier," which is the claim of student B. Nadia thought student A was the most convincing, and also agreed with student A's claim that "the inflated [soccer ball] is heavier [than the flat one]."

Students were asked to write down the reasons for their decisions. Analyzing their written reasons revealed some patterns. First, some of the students tended to repeat the claim that they agreed with. For example, Zhao thought student D (i.e., both soccer balls weigh the same because air does not weigh anything) was the most convincing because "the inflated soccer ball and the flat one have the same weight, no difference" (students' writings, 2018/05/04). Ivan chose student B, who was arguing that the flat soccer ball was heavier, as the most convincing one; in his written response explaining the reasons, he wrote, "if he has an inflated soccer ball, it is lighter than the deflated" (students' writings, 2018/05/04). Some other students tended to supplement the evidence to further justify the claim they agreed with. For example, Nadia thought student A (i.e., the inflated soccer ball is heavier because it has both leather and a lot of air) was the most convincing one. When she was asked to explain the reasons for her decision, she agreed with its claim (i.e., the inflated ball is heavier) and wrote "because they both have the same amount of leather, and the inflated one also has air, if air has weight, so the inflated soccer ball is heavier" (students' writings, 2018/05/04). Similarly, Nate explained that he thought student A's argument was the most convincing "because the inflated [soccer ball] is heavier. It is heavier because it has air and leather, and the flat one has no air, so it only has leather which makes it lighter" (students' writings, 2018/05/04).

From the analysis, it seemed students thought the argument with the claim that they agreed with was the most convincing one. In other words, it seemed as if students only examined whether the claims in the arguments were correct or not as they made their decisions about whether the argument was convincing or not and chose the one with the “correct” claim. This is similar to the results reported in previous studies that students usually focus on the correctness of a claim, rather than looking at the relationship among question, claim, and evidence (e.g., Choi et al., 2010; Takao & Kelly, 2003). Scholars (e.g., Kuhn et al., 2013) have argued that it indicates that students have poor argument evaluation competence if they evaluate claims alone without determining if available evidence is valid, relevant, sufficient, and convincing enough to support the claim. According to Kuhn et al. (2013), however, students often tend to do this because they are inclined “to simply evaluate the content of a statement” (p. 474). In their study, Kuhn and colleagues categorized and coded students’ performances in argument evaluation as “evaluation of claim alone” if students only examined whether the content of the claims was correct or whether they agreed with the statements or not (p. 475).

With the aim to investigate closely how they made their argument evaluations, I further analyzed their descriptions in the SRIs of their thinking processes while making decisions. These analyses helped me better understand how students evaluated arguments that were developed by others. Analyzing these data revealed that, even if students eventually chose and wrote down the argument with the “correct” claim as the most convincing one, their thinking processes were complicated, or at least not simple, and their Mc-A was involved in the process of evaluating arguments. In the next two illustrating examples, Nate and Ivan both chose the argument with the “correct” claim as the most convincing one. Regarding whether a flat or an inflated soccer ball is heavier, they had different answers. Therefore, their choices of the most convincing argument were different too. Moreover, both of them demonstrated that their Mc-A was involved while they were evaluating these arguments and making their choices; yet, their thinking processes and how their Mc-A was involved were different from each other.

Example #10: Nate's argument evaluation (the first part)

Table 5.7-1 *Nate's written answer in the argument evaluation task*

Line #	**Nate's Argument Evaluation Task** (Students' writing, 2018/05/04)	**Analysis Notes** (i.e., My Interpretation)
	Part 1: (choosing the most convincing argument from Student A, B, C, and D)	
01	I think student A is the most convincing.	His choice about the most convincing argument. He chose *Student A: "the inflated soccer ball is heavier because it has both leather and a lot of air"* as the most convincing argument
02	Because the inflated one is heavier. It is heavier because it has air and leather, and the flat one has no air, so it only leather which makes it lighter.	Evidence-based defending (for his choice)
03	My thinking process is I know air has weight from the classroom learning, so student A is correct. I agree with student A.	Reporting his thinking process

The first example is Nate's argument evaluation. Table 5.7-1 above shows Nate's written answers in this argument evaluation task (the first part), and Table 5.7-2 below is what he shared during the SRI regarding how he made his choice. When he chose Student A's argument (i.e., "the inflated soccer ball is heavier because it has both leather and a lot of air") as the most convincing one, Nate was aware that he had learned "air has weight" from previous science classes, so he confidently knew "the inflated one is heavier"; that is, he knew student A had the correct claim and agreed with student A (Line #02, #03). Then, with his McK-A—"if [the claim] is not correct, it [the argument] cannot be convincing" and "to be convincing, you need to . . . be correct" (Line #06)—he made his decision that the argument having the "correct" claim was the most convincing (Line #07). Based on what Nate shared thus far, it seemed his argument evaluation was "evaluation of claim alone," which is seen as an indicator of "poor [argument] evaluation" (Kuhn et al., 2013, p. 475). However, Nate's argument evaluation revealed that, even in the "evaluation of claim alone," there was a complicated thinking process involved, as well as Nate's Mc-A. As the interview went along, Nate mentioned that he had examined the evidence and justification in student A's argument too, even though he didn't write it down in the worksheets. He explained that "student A did not really explain well" and lacked critical evidence, which was that "air has weight" and she "should clearly say" it (Line #08).

Table 5.7-2 *Nate's self-reported thinking process of evaluating arguments*

Line #	**Transcript of SRI with Nate** (Interview transcript, 2018/05/04)	**Analysis Notes** (i.e., My Interpretation)
04	A is most convincing, because A is correct. You know, air has weight, so the inflated one is heavier.	Evidence-based defending (of his choice)
	Researcher: How did you know air has weight?	
05	I learned from science class that air has weight. I know it.	(possible) Indicator or *metacognitive monitoring* [knowing he knew air has weight and knowing he learned it from classroom science learning]
06	. . . the answer [the claim] should be correct. If it is not correct, it cannot be convincing . . . to be convincing, you need to be correct.	Indicator of *declarative McK-A* [knowing the convincing argument needs to have correct claim]
07	So, I chose A [as the most convincing] . . .	Made his decision
08	but A did not really explain well, like, "a lot of" what does it mean? She should clearly say that it is because air has weight, just like student E, then, it will be much better . . .	Indicator of *procedural McK-A* [knowing how to justify]

Example #11: Ivan's argument evaluation (the first part)

The second example is Ivan's argument evaluation. Ivan thought student B's argument (i.e., "the flat one is heavier, I have evidence. I play soccer ball and I cannot kick the flat ball as far as the inflated one, so the flat one must be heavier") was the most convincing; he wrote on the worksheet "because if he has an inflated soccer ball, it is lighter than the deflated" (students' writing, 2018/05/04). During the interview, Ivan was asked to elaborate on how he made his decision, and he explained how he thought. According to what he shared, when he read student B's evidence, he realized the evidence was convincing to him. He said "I have the same experience. I play soccer . . . the moment I read his [student B's] evidence, I knew it is correct, believe me, so it is the most convincing." Then, he elaborated that "[because] the evidence he [Student B] used is correct, so it is most convincing" (McK-A). Finally, because he thought student B's argument was "the most convincing," he concluded that "B is correct" (McK-A) (Interview transcript, 2018/05/04). In other words, for Ivan, the process of his argument evaluation was as follows: he examined the evidence first, and then chose the argument with the most persuasive evidence as the most convincing one; finally, he determined that the most convincing argument was correct. He thought the most convincing argument answered the question correctly, rather than choosing the correct argument as the most convincing.

Through comparing these two examples, it was found that both Nate and Ivan chose the argument that made the "correct" claim (they thought) as the most convincing one, and both their Mc-As were involved in their argument evaluation. However, their thinking processes and how their Mc-As were involved were different from each other. For example, Nate thought the argument was convincing because it was correct; however, Ivan thought that because it was convincing, then the argument was correct. In addition, SRIs with them also showed that the processes of their argument evaluation were more sophisticated than what was represented in their written answers.

Thus far, I have described how students performed argument evaluation and how their performances were related to their Mc-A while they were working on the first part of the evaluation task. Next, I describe how they performed and thought during the second part of the task.

5.3.2 Evaluating Arguments with the Same Claim

The second part of the argument evaluation task (refer back to Figure 4.4) asked students to choose the more convincing argument from two arguments that made the same claim but with different evidence or reasoning. The involvement of students' Mc-A was more explicit in this second part compared with the previous first part of the argument evaluation task.

To this question (i.e., which one is more convincing?), students also provided different answers. Two students thought student A was more convincing, and the other 14 students preferred student E as the more convincing one. Even if they made different choices, the writings and interviews with both groups of students revealed that their Mc-A was involved while they were examining arguments in light of, for example, the sufficiency of evidence and the quality of reasoning. For example, David thought student E was more convincing, and his written reasons were "because E has more evidence and uses more convincing words, such as 'same amount'" (Students' writings, 2018/05/04). In the in-class informal interview with him, he also shared that he made his choice through "us[ing] [his] knowledge about how to be persuasive" (procedural McK-A) (in-class informal interview transcript, 2018/05/04). Zhao chose student A as the more convincing one because "A is more concise, easier to understand; E said more, but too much . . . some of her evidence is wrong, not reliable, so not good" (Students' writings, 2018/05/04). During the in-class informal interview, Zhao described his thinking as "I am comparing both, I am using my logic and [my knowledge about] what is good evidence" (procedural McK-A) (in-class interview transcript, 2018/05/04). SRIs with students also confirmed the involvement of Mc-A in their argument evaluation. For example, during the SRI, Nate shared that, when he was completing this second part of the evaluation task, he first examined the claims of both arguments. After he noticed that both arguments made the same claims, or, in his words, “they [were] both correct,” he started to examine the evidence and justification, because he knew that “evidence and how you explain [were] important for being convincing” (indicator of *declarative McK-A*, knowing the importance of evidence and justification). In other words, being aware of the significance of evidence and reasoning affected his behaviour of examining the evidence and reasoning that were included in these arguments. In this way, his Mc-A was involved in completing his argument evaluation.

As I reflected on the research methods in Chapter 3, I acknowledged that interviews with the aim to access students’ metacognition would influence their metacognition, because the probing and questioning in these interviews would stimulate students’ metacognitive experiences (Thomas, 2012). Through examination of the interviews in this study, I discerned some episodes that could illustrate the influence of the interviewer (i.e., myself) on students’ Mc-A. Next, I provide an example, which was a part of the SRI with Jaden about his argument evaluation.

Example #12: Jaden’s argument evaluation (the second part)

After the students completed their argument evaluation tasks, Jaden was invited to participate in an SRI and share his thinking processes of evaluating these arguments. When he was explaining how he had decided that student E was more convincing than student A, the following conversation (in Table 5.8-1) between Jaden and me took place.

Table 5.8-1 *SRI with Jaden about his thinking process of evaluating arguments*

Line #	**Transcript of SRI with Jaden** (Interview transcript, 2018/06/18)	**Analysis Notes** (i.e., My Interpretation)
	Researcher: Can you describe your thinking process of making your decision choosing E as the more convincing one?	
01	Like, student E is this long [showing with his fingers that student E has many lines of words], while, student A is only this long [showing with his finger that student A has fewer lines of words], so it is obvious that E is more convincing.	Indicator of *declarative McK-A* [knowing the longer argument with more words is more convincing] (initially reported) *OR* Indicator of *procedural McK-A* [knowing how to evaluating arguments through examining the length of arguments] (initially reported)
	Researcher: . . . this is the thinking process of your decision making at that time, right?	My *questioning & prompting* on his thinking explicitly
02	Yes.	
	Researcher: So, your way of thinking is to examine which one has more words. You think the more words the more convincing, right? If I said more, a lot a lot and a lot, then it will make whatever I said more convincing, you mean this?	My *questioning & prompting* on his thinking explicitly
03	Yes. [thinking for a few seconds] No, wait, hmm. No, let me think. [thinking for many seconds]	(possibly) Indicating that he was reflecting on his own thinking process and McK-A
04	No. I think E is more convincing, because, yes, she said more, and that helps. But, she also gave more evidence and, like, explained better. She did not, like, just blahblahblah, she had evidence.	Indicator of *declarative McK-A* [knowing the importance of evidence and justification] (changed) *OR* Indicator of *procedural McK-A* [knowing how to evaluating arguments through examining the evidence and justification in the arguments] (changed)
	Researcher: Then, when you think back now, did you make your choice only because E said more than A?	My *questioning & prompting* on his thinking explicitly
05	No, I think . . . No. I remember that when I read student C, I thought he was just like blahblahblah, said a lot a lot, but nothing really make sense. But not student E.	Recalling his thinking process back then
	Researcher: So, you mean that you examined whether student E was just	My *questioning & prompting* on his thinking explicitly

	blahblahblah *or her evidence made sense, right?*	
06	Yes, I think I examined her evidence. So, can I change my answer on this?	Recalling his thinking process back then

Jaden said he thought E was more convincing because E had said more and her argument was longer than A's (Line #01). When I further questioned his thinking process by repeating and rephrasing his words, for example, asking him "you think the more words the more convincing, right?", he was challenged, and thus rethought his thinking process at the time (Line #03). That is, my questions and cues stimulated his metacognitive experiences. Then, he realized that when he made his decision, he also examined the quality of E's words, that is, whether E used supportive evidence or whether her evidence made sense (Line #04, #05, #06). In this way, during the interview and with my questions about his thinking process at the time, his self-reported McK-A that was involved in the process of argument evaluation changed.

With the SRIs, it was found that some students (e.g., Nate [see Table 5.6-3, 5.7-2]; David [see Table 5.2-2]; Levi [see Table 5.1-2]) were not only aware of their Mc-A but were also capable of describing, sharing, and discussing it with the researcher. However, some other students may not have been aware of their thinking processes, thus their retrospectively self-reported thinking process might be not reflect how they actually thought. Then, with the researcher's explicit questioning or prompting, they would recall more accurately their thinking back then. In this way, the interviewer's questioning and prompting stimulated their metacognitive experiences and affected their Mc-A. Therefore, as discussed previously, I acknowledge that the SRIs and in-class informal interviews, as data collection methods to gain relevant information about students' Mc-A in this study, were not neutral; instead, they could and did influence students' metacognition.

After this argument evaluation task, which was also the second focused activity, and several linking lessons (see Table 4.1 for more information), the teacher and students came to the last focused activity: the parachute & glider design, testing, and improving project. In this group problem-solving context, students' argumentative dialogues also took place. The next section describes students' argumentative dialogues in this last focused activity.

5.4 Argumentative Dialogues in the Third Focused Activity

In this section, I first describe students' argumentative dialogues that took place in a group problem-solving context in the third focused activity. Then, with illustrating examples, I describe how students refined their McK-A and transferred their McR-A, particularly metacognitive monitoring, from their previous learning experiences into this new learning task.

5.4.1 Resolving Differences Through Argumentative Dialogues

At the beginning of this activity and before the students were assigned into groups, there was a teacher-led whole-class discussion about how they could think and do during their group problem solving, especially when they had different ideas (science class on 2018/05/25; see Appendix D-6 for full transcript). With the teacher's scaffolds, students explicitly expressed that they would discuss with evidence. For example, David mentioned that "everyone in the group should have the chance to express . . . and we, a team, compare the evidence and make our decision"; and Ivan said "[when we have different ideas] we can discuss, we can take the turn to say our ideas . . . discussion can solve [the disagreement] because reasons and evidence are always important." Then, after the teacher confirmed key ideas about resolving differences through argumentation, saying "we communicate with evidence and respectfully," students started their group work on designing, testing, and improving their parachute models.

During the teacher-led whole-class discussion, both David and Ivan expressed that they were aware of the importance of evidence and knew how to resolve their differences when they had different ideas. Particularly, both of them had mentioned that they could and should examine evidence to reach an agreement. However, even if they articulated the same or similar ideas, they performed differently when they were working with classmates in small groups.

Example #13: David's group decided on the shape of the canopy

During this activity, David was working together with Zhao, Kenny, and Kelvin. When they were deciding the shape of their parachute canopy, different ideas appeared in their group and the following argumentative dialogue took place (see Table 5.9-1).

Table 5.9-1 *Argumentative dialogue among David's group*

Turn #		**Argumentative dialogue (David's group)** (Classroom recording transcript, 2018/05/25)	**Analysis Notes** (i.e., My Interpretation)
01	David:	We can make it circular. What do you think?	Claim making Asking other students in the group to express and share their ideas
02	Zhao:	Why not rectangular?	Counter-claim making
03	David:	You have reasons [for the rectangular one]?	Asking for evidence
04	Kenny:	Yeah, real parachutes are rectangular.	Evidence-based supporting
05	David:	What do you think, Kelvin?	Asking other students in the group to express and share their ideas
06	Kelvin:	I agree with you, circular.	Simple supporting
07	David:	You know, the rectangular one is for the person to change the direction . . . we do not need to change the direction.	Evidence-based rejecting
08	Kelvin:	Yes, and the circular one has a bigger surface.	Evidence-based supporting
09	Kenny:	OK, then, the round one.	Consensus achieved
10	Zhao:	[nodding]	
11	David:	I am writing it down in the document, circular.	

After David proposed that they could make it circular, he immediately asked what other students thought (Turn #01). After Zhao indicated that he wanted the canopy to be rectangular (Turn #02), David asked him whether he had any reason for preferring the rectangular shape (Turn #03); that is, David was asking for evidence for an idea that was different from his. Zhao did not say anything, but Kenny supported Zhao and provided evidence, saying that "real parachutes are rectangular" (Turn #04). Then, noticing that Kelvin had not said anything, David asked him what he thought (Turn #05). Kelvin agreed with David about the circular shape (Turn #06). Next, David provided his evidence for why they didn't need the rectangular shape: "the rectangular one is for the person to change the direction," which was not necessary or possible for their parachute model (Turn #07). David's evidence, together with the supplementary evidence from Kelvin that "the circular [shape] has bigger surface" (Turn #08), convinced Zhao and Kenny. Finally, they decided they were going to build a circular parachute canopy. As shown in this episode, David as the group leader organized the group's argumentative dialogue. He asked each of them to express their ideas, then asked for and provided evidence. Finally, as a team, through this argumentative conversation, they made their evidence-based final decision, on which they all agreed.

Example #14: Ivan's group made their decision on the number of the shroud lines

Ivan was working with Jeff and Jayraj as a group. When they were deciding the number of the shroud lines, different ideas appeared (see Table 5.9-2 below). Ivan proposed that they should have 10 shroud lines (Turn #12). After Jayraj expressed his idea, which was different from Ivan's (Turn #13), Ivan simply rejected it without any evidence or reason, and insisted on his idea (Turn #14). When Jayraj tried to ask what Jeff thought (Turn #15), Ivan interrupted and directly made the decision, ignoring other group members' thoughts (Turn #16).

Table 5.9-2 *Argumentative dialogue among Ivan's group*

Turn #		Argumentative dialogue (Ivan's group) (Classroom recording transcript, 2018/05/30)	Analysis Notes (i.e., My Interpretation)
12	Ivan:	We should have 10 [shroud lines].	Claim making
13	Jayraj:	Is that too much? How about 4, 1 on each corner?	Counter-claim making
14	Ivan:	No, it should be 10, we need 10.	Simply defending
15	Jayraj:	What do you think, Jeff?	Asking other students in the group to express and share their ideas
16	Ivan:	We are going to have 10. [he wrote 10 down in the planning document]	Ignoring other students' ideas

Both David and Ivan articulated during the teacher-led whole-class discussion that when they had different ideas, they could and should discuss them with evidence. However, in the actual group work, when different ideas emerged, they performed in different ways. During the second SRI with David, the episode including his group's argumentative dialogue (shown in Table 5.9-1) was shown to him. Within this interview, David shared:

> David: I was thinking, like, it is always important that everyone has the chance to express their ideas and their evidence . . . we talked in class that . . . this is how people work as group . . . you cannot vote . . . Yes, we talked in class it is the good way to . . . make decision. We can compare and make a *better* decision [he stressed the words in italics] … I think they agreed with me because I said this, my evidence . . . evidence is always important, like in the NASA project . . .
> (Interview transcript, 2018/06/18)

As David said, he organized the group to discuss with evidence because he knew "it is always important that everyone has the chance to express their ideas and their evidence" as "this is how people work as group" to "make a *better* decision" (he stressed the word in italics). In this way, he demonstrated that while he was engaged in argumentative dialogue with his groupmates, his McK-A was involved, both the procedural McK-A about how to resolve difference through argumentation, and conditional McK-A about why to do it in this way. Moreover, regarding his

McK-A, he elaborated and related it to their classroom discussion, in which the teacher's scaffolds were integrated. He stated that he knew it and applied it because "[they] talked in class" that it was a good way to make decision.

The in-class informal interview with Ivan also provided some information about Ivan's thinking while his group was deciding the number of the shroud lines. For Ivan, even though he had expressed, during the teacher-led whole-class discussion, that when they had different ideas they could and should discuss them with evidence and reasons, he did not perform in that way. He did not (or may not have) considered his groupmates' ideas because he thought "[they] do not need to discuss . . . and 10 [his idea] is the best" (in-class informal interview, 2018/05/30). Ivan's observed behaviours and what he shared during the interview were consistent, indicating that he did not apply his knowledge about resolving differences through argumentation in the actual group problem-solving task. However, with the available data, it is difficult to infer whether he was unable to retrieve and apply that knowledge or he deliberately decided not to apply it.

In sum, facilitated by the teacher's scaffolds during the classroom discussion, David and Ivan both articulated their knowledge about how to resolve differences through argumentation. However, when they were actually engaged in group problem solving, David applied his McK-A to regulate his behaviours and their group's discussion, and Ivan did not. I have not presented these two examples in parallel to determine which student's performance was better. Instead, the purpose was to illustrate that (1) in the collaborative problem-solving context, students' argumentative dialogues took place spontaneously; (2) some students' Mc-A was involved in the argumentative dialogues in this problem-solving context; and (3) students also attributed their Mc-A to the teacher's instructional scaffolds.

5.4.2 Students Refined McK-A in the New Learning Task

In this section, I present an example to illustrate how students refined their McK-A through examining their task performance and reflecting on the applicability of their (existing) McK-A in the new context.

Example #15: David refined his McK-A in the new learning task

After learning the units Air & Aerodynamics and Flight, students were assigned into various groups to design, test, and improve their parachute models. The teacher and students all agreed to do the final test with quail eggs; that is, they decided that a quality parachute should be able to land quail eggs safely from the second floor of their school building. Through group discussion, David's group, including David, Kelvin, Kenny, and Zhao, completed their planning document and started building. During the process of building and testing their parachute, they changed a lot regarding their design, such as the materials of the canopy and the number and length of the shroud lines. During the second round of SRIs (see Table 5.10-1 below), David shared how and why they had made these changes during the building and testing with their Mc-A being involved, especially the knowledge aspect: McK-A. Moreover, David shared how he (or his group) found that the previous McK-A "just [did] not work" in the new learning task and how he/they refined their McK-A through his/their reflection on their task performances and examination of the new problem-solving context.

Table 5.10-1 *David refined his McK-A in the new learning task*

Line #	**Transcript of SRI with David** (Interview transcript, 2018/06/18)	**Analysis Notes** (i.e., My Interpretation)
	Researcher: . . . what was your thinking process during the parachute model designing? How did you think? . . .	
01	. . . Kelvin and I found that the real parachutes are made of nylon . . . as we were making our parachute [model], so we researched on the real ones . . . the design of the real	Sharing how they collaborated in this project

	parachutes . . .	
02	. . . We were thinking, you know, if we use the same [materials] as the real [parachutes], then, it could be more convincing.	Indicator of *procedural McK-A* [knowing how to be convincing and to prove that their parachute model was good]
03	. . . We got some useful information from NASA's website too. NASA also make parachutes.	
04	. . . [we made the changes] after we tried. 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 eggs . . .	Examining their task performance
05	Using the information from NASA and the same materials as the real one sounds like cool, but . . . in this project it cannot prove our parachute is good, cannot make our small one good . . .	Reflecting on the "old" procedural *McK-A* about how to be convincing, and realizing that it did not work in the new situation
06	We can prove that if our eggs are good . . . not broken, and, if our parachute can carry more eggs, three maybe, we only tried two, then it is a good parachute . . .	Indicator of "new" *procedural McK-A* [knowing how to be convincing and to prove their parachute model was "good"]
07	. . . we do not need to convince other people, like the NASA pitch, using good information from the online research. [in this activity] if our egg was broken, then it [our parachute] is not good.	Indicator of "new" *procedural McK-A* [knowing how to be convincing and to prove their parachute model was "good"] Comparing the new context with the previous one
	Researcher: . . . you realized "how to be convincing" was different in these two projects, right? How did you know this?	
08	It just does not work, like, using the nylon. Even NASA is using that, other real parachutes are made of nylon too, but it falls very fast, just fail to protect the eggs . . . you saw when we tested it, right, it is just like, shu [he was describing how fast their nylon parachute landed on the ground through imitating the sound and showing with his body movement] all the eggs will be broken, like, it just does not work . . .	Examining the task performance Reflecting on the "old" *McK-A* about how to be convincing Confirming that the "old" McK-A did not work
	Researcher: . . . how did you get the idea of using the plastic bag?	
09	Just think how to make it lighter, the lightest . . .	

When this group of students started the parachute design project by working on a planning sheet, with their (existing) McK-A (e.g., knowing that they need reliable evidence and NASA's website is a good source of reliable evidence), they explored NASA's website to find reliable evidence to support their design. After they learned from NASA's website that NASA's real parachute canopies were made of nylon (Line #01), they proposed that they would use the same material to build their parachute model, because they thought "if [they] use[d] the same [materials] as the real [parachutes], then, it could be more convincing" to show that their parachute was "good" (Line #02). However, when they tested their parachute, they found that the nylon canopy was too heavy to land slowly and protect their quail eggs (Line #04). Then, according to what David said, through examining the new context and reflecting on their task performances, they realized that good or reliable information from authentic data sources such as NASA was not convincing to prove their parachute was "good." Instead, whether they could land the quail egg(s) safely and carry more eggs was the more convincing evidence for whether their parachute was a "good" one or not (Line #05, #06, #07). Then, with their refined McK-A about how to prove their parachute model was "good," they 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 (Line #09).

5.4.3 Students Transferred Metacognitive Monitoring into the New Learning Task

Data analysis also revealed that students transferred their McR-A, particularly metacognitive monitoring, into this new learning task as well (i.e., the third focused activity). As described previously, students demonstrated their abilities of metacognitive monitoring while they were engaged in argumentative dialogues during the NASA technology design project.

They monitored their comprehension through asking themselves questions such as "Do I understand this?" and "Does this make sense to me?" During that activity, students also attributed their metacognitive monitoring to the teacher's instructional supports. Students said they knew how to monitor their comprehension because the teacher showed and reminded them to do so.

When they came to the third focused activity, while students were working as small groups to build parachute models, their metacognitive monitoring was found to be involved in the process as well. Similarly, they monitored their comprehension through deliberately asking themselves questions. Instead of being reminded by their teacher, students in this activity initiated their metacognitive monitoring because they realized that they needed "to be focused." In this way, they transferred their metacognitive monitoring into this new learning task. What follows are two illustrating examples showing how students' metacognitive monitoring was involved in their group's collaboration.

Example #16: Nadia's metacognitive monitoring in this new learning task

Nadia was working together with Luis and Xander as a small group on this parachute project. While they were trying to decide on materials for the canopy of their parachute model, argumentative dialogue (see below) emerged as different ideas appeared.

> Xander: We can use balloons . . . we could put four or six balloons together as the canopy . . . you know, that will work, because balloons are very light.
> Luis: We should use this plastic bag [he was holding a plastic garbage bag].
> Xander: No, that won't work, that is not a good idea. No, we cannot use a garbage bag, we should use balloons, because balloons are light, very light.
> Nadia: I do not think I understand you, Xander. You mean balloons are light, so you want to use balloons, right? But the garbage bag should be lighter [than balloons].
> (Classroom recording transcript, 2018/05/28)

Xander proposed to use balloons to make the canopy because he thought "balloons are very light." Luis proposed that they should use the plastic garbage bag as the canopy. Then, Xander started to reject Luis's idea, saying "No, we cannot use a garbage bag, we should use balloons, because balloons are light, very light." Hearing Xander's words, Nadia expressed her confusion by saying "I do not think I understand you, Xander. You mean balloons are light, so you want to use balloons, right? But the garbage bag should be lighter [than balloons]."

During their discussion, I noticed that Nadia said to Xander "I do not think I understand you . . ." I took this as a verbal indicator of metacognitive monitoring (i.e., Nadia was monitoring her comprehension and realized that she did not understand). Therefore, when they were working individually, I initiated an in-class informal interview with her to learn her thinking process while she was in that discussion. I asked Nadia "How did you find that you did not understand Xander? What was your thinking process at that moment?" She responded:

> Nadia: I was thinking, I just tried, I was trying to understand [them] . . . just when I heard they had different ideas . . . I think I need to focus, because, you know, they will ask me, what do I think . . . as we only have three [people in our group] . . . so I just think whether that make sense or not, I asked myself before I asked him [Xander] . . . they were kind of against each other, so I need to make sure I understand them correctly, so that we can make the right choice . . . usually, when two people agree on this, for example, the balloon, we will go with the balloon . . .
> (In-class informal interview transcript, 2018/05/28)

With these words, Nadia confirmed that at that moment she was monitoring her own comprehension. Her examination of the situation that they were in initiated her metacognitive monitoring. Nadia realized that her two groupmates "were against each other," thus what she thought would be critical to making their final decision, because in a group of three they usually went with the idea supported by two people when they had differences. Therefore, she monitored her comprehension to make sure she understood her groupmates correctly, so that she could make her decision.

Example #17: Jayraj's metacognitive monitoring in this new learning task

Jayraj was another example illustrating how students transferred their metacognitive monitoring into a new learning context. During the semistructured interview with him, Jayraj shared how Ms. Bowen's scaffolds (i.e., telling them what they should think while listening to others) helped him "be a good audience" and ask constructive questions of his peers. When I asked him whether he had used that strategy (i.e., asking himself questions such as "Does this make sense to me?" "Do I understand this?") after the NASA technology design project, he responded:

> Jayraj: Yes. (Researcher: when?) . . . like, in class and group talk, you always need to listen carefully and think whether you understand . . . You know, Ivan always has . . . some strange ideas, he is a . . . mysterious person . . . like the 18 meters and 18 centimetres thing, you were there, right? [During their parachute design, Ivan found online that a real parachute had 18.47-metre-long shroud lines, so he said the best choice of their parachute model was to have 18.47-centimetre-long shroud lines.] So, whenever I work with him I remind myself to think, okay, does he [his ideas] really make sense? Do I really understand what he is talking about? . . . "
> (Semistructured interview transcript, 2018/06/18)

As Jayraj said, when he was working in a group, he monitored his comprehension by reminding himself to think about questions such as "Do I really understand what he is talking about?" With this description as an indicator, Jayraj demonstrated that his metacognitive monitoring was involved while he was working in his group. Moreover, according to what Jayraj said during the interview, he questioned himself about his own comprehension because he knew what situation he was in: he was working together with Ivan, whom he thought was a "mysterious person" with "some strange ideas." In other words, he connected his metacognitive monitoring to his examination of his learning context, such as whom he was working with and the characteristics of his groupmate(s).

As shown in these two examples, both Nadia and Jayraj initiated their metacognitive monitoring when they realized the necessity of "being focused," which resulted from examining the situations that they were in. In this new learning task, they employed the self-questioning strategy that they had learned previously to monitor their comprehension. In this way, they transferred their metacognitive monitoring into a new context.

In this chapter, I presented the main findings of this study. With illustrating examples, I described how students' Mc-A, both the knowledge and regulation aspects, was involved in various kinds of argumentation, including individual argument construction, argument evaluation, and the dialogical form of argumentation, as well as how students thought about their Mc-A. In the next chapter, I discuss these findings further.

CHAPTER 6

DISCUSSION

The goal of this study was to investigate how elementary students participated in argumentative practice and to explore students' metacognition in the context of argumentation (Mc-A) when argument-focused metacognitive scaffolds were integrated into the science classroom as a part of everyday science instruction. The findings suggest that while students were engaged in argumentation, their Mc-A was involved in the process. In various kinds of argumentation, including argument construction, argument evaluation, and argumentative dialogue, students' Mc-A was related to their decision making regarding how they would think and do. Students' Mc-A usually manifested when their thinking process was explicitly talked about, such as within the interviews with the researcher and classroom conversations with their teacher and peers. Regarding their Mc-A, students tended to attribute it to the teacher's classroom instruction in which the scaffolds were integrated and their reflections on their task performances and examinations of the (new) learning contexts.

This chapter begins with a discussion of the main findings in relation to the two research questions of this study. Then, the study's theoretical and pedagogical contributions are discussed. Finally, suggestions for future research worthy of consideration and my reflections on conducting this research study are provided.

6.1 Research Question #1

The first research question in this study is: How is students' Mc-A involved in argument construction, argument evaluation, and argumentative dialogue in science classrooms? This question sought to investigate how elementary students participated in various argumentative practices, including argument construction, argument evaluation, and argumentative dialogue between/among students in a grade 5/6 science classroom.

Examination of various data reveals that elementary students were capable of participating in productive scientific argumentation with appropriate and sufficient supports. For example, most of the fifth-/sixth-graders in this study constructed their arguments around space technology design through justifying their claims with sufficient, relevant, timely, and valid evidence. When elementary students were given scaffolds and opportunities to learn and practice argumentation, they were capable of understanding argumentation, including its goals and norms, and of linking these understandings with their actual argumentative practice. This finding suggests that elementary students' argumentative practice can go beyond "doing the lesson" (p. 757), as proposed by Jiménez-Aleixandre et al. (2000). Nevertheless, teaching students argumentation can be a long-term process. Improvements in students' abilities to understand and perform argumentation do not come naturally to most individuals, but rather grow through practice (Chen et al., 2016).

Data analyses further revealed that students' Mc-A was involved in argumentation as it affected students' decision making regarding how they would think and do while they were engaged in argumentation. In what follows, I first summarize how Mc-A was involved in various argumentative practices. Then, the diversity and complexity of Mc-A's involvement is discussed.

6.1.1 Students' Mc-A Was Involved in Argumentation

First, findings from this study suggest that students' Mc-A affected their argument construction. Knowing that the goal of argument construction was to persuade their audience (McK-A), students thought about how to be convincing. Then, they came to understand that, to be convincing, they needed evidence (McK-A), especially "good evidence." With this awareness of the necessity and importance of evidence (McK-A), they started their evidence searching online to justify their claims. The teacher showed them how they could think to frame their claims. Students took the teacher's suggestions and adjusted their thinking (metacognitive control) to frame their claims by deliberately connecting their personal interests with their knowledge about current space exploration. Moreover, they also knew their own criteria for "good evidence" (McK-A), as well as their own strategies for finding "good evidence" and justifying their claims (McK-A). With their diverse metacognitive knowledge about evidence and justification, students searched for evidence online and justified their claims in diverse manners. In this way, students' McK-A and metacognitive control were involved in the process of their argument construction.

Second, how students evaluated different arguments was also related to their Mc-A. They knew the necessity and importance of evidence (McK-A), so they examined whether these arguments had supportive evidence or not. They knew that "good evidence" needed to be valid (McK-A), thus they examined the accuracy and validity of evidence that was cited in the arguments to support claims. In addition, because they knew that how to justify was important (McK-A), they examined the justification in these arguments as well. Based on the results of examining evidence and/or justification in various arguments, they made their decisions about the argument evaluation. In this way, students' Mc-A, especially McK-A, was involved in evaluating arguments.

Finally, Mc-A also affected students' argumentative dialogues. Through monitoring their own thinking and comprehension (metacognitive monitoring), students realized that they held different ideas or that others' arguments did not make sense to them, thus they were not convinced. Then, they raised questions or counterclaims, and argumentative dialogue took place. As the argumentative dialogue developed, students' McK-A was also involved. Knowing the necessity and importance of evidence (McK-A), students provided evidence to defend their own claims and examined that evidence that was cited to support the counterclaims. Through monitoring their own comprehension again, students knew whether they were convinced by the evidence provided by their peers. Then, if they knew they were convinced, they would change their ideas and accept new ones; otherwise, they would keep their initial ideas.

To sum up, how elementary students participated in various argumentative practices in the science classroom was related to their Mc-A, both the knowledge and regulation aspects. These discerned close relationships between students' Mc-A and their performances in argumentation, as empirical evidence, support the assertion that metacognition is important for argumentation, which has been theoretically proposed and widely accepted in the literature (e.g., Duschl, 2008; Garcia-Mila & Anderson, 2007; Jiménez-Aleixandre, 2007; Zeidler & Sadler, 2008; Zohar, 2007), yet to date has lacked supportive empirical evidence.

6.1.2 Diversity of the Involvement of Students' Mc-A in Different Argumentative Practices

Students' Mc-A was involved in argument construction, argument evaluation, and argumentative dialogue, but in diverse manners. As summarized and discussed above, the knowledge aspect of Mc-A (i.e., McK-A), especially students' McK-A related to evidence, was evidently involved in all three practices of argumentation and closely related to students' decision making during the processes. However, difference was found in the involvement of McR-A in these argumentative practices. The following two patterns were discerned: (1) *metacognitive monitoring*, especially monitoring one's comprehension, was more frequently involved in the argumentative dialogues than argument construction and argument evaluation, which were completed by students individually; and (2) *metacognitive control* was found to be involved in the argument construction within the first focused activity, yet was rarely discerned in either argument evaluation or argumentative dialogues.

Why indicators of students' *metacognitive monitoring* were more frequently discerned during the argumentative dialogues might be related to the unique characteristics of this dialogical form of argumentation. During argumentative dialogues, like the ones in this study, students are asked and expected to explain their ideas, rationales, and thinking processes immediately and explicitly to other interlocutors. When students engage in this kind of dialogue, according to Kuhn (2010), they "must simultaneously process the other's contribution and anticipate his or her own response to it, and do so successively over what may become an extended sequence of turn-taking" (p. 813). In other words, being engaged in an argumentative dialogue requires students to give instant reactions to their interlocutors, which are usually and supposed to be based on their comprehension of what their interlocutors said, and to "do so successively" (Kuhn, 2010, p. 813). Therefore, students' ongoing monitoring of their own comprehension to make sure they comprehend their interlocutors (or not) is critical to the development of the argumentative dialogue. Argument construction and argument evaluation might also require students to "process the other's contribution" and/or "anticipate [and provide] his or her own response," yet they do not necessarily "do so successively" (Kuhn, 2010, p. 813). Thus, the ongoing monitoring of one's own comprehension in either argument construction or argument evaluation might be not as critical as in argumentative dialogue. This might help to explain why *metacognitive monitoring* was more frequently discerned during the argumentative dialogues than in the other argumentative practices.

Metacognitive control was rarely discerned in this study, except during argument construction in the first focused activity. Two main reasons could help explain this. The first is how metacognitive control was defined in this study. Metacognitive control in the context of argumentation refers to students' conscious adjustment of their own *thinking* during argumentation. Thus, students' regulations or adjustments of their behaviours on the cognitive level were not interpreted or coded as metacognitive control in this study. During the data analysis, it was commonly discerned that students adjusted their behaviours on the cognitive level. For example, students knew they needed valid evidence and thought NASA was a reliable source for valid evidence, so they would particularly explore NASA's website to collect their evidence. In this way, they regulated the ways of searching evidence on the cognitive level. According to the limitation of metacognitive control in this study, however, it was not interpreted as metacognitive control. The other possible reason to help explain why metacognitive control was rarely discerned is the teacher's scaffolding. During the first focused activity, the teacher taught students how to think in order to choose technologies that were "both realistic and innovative." Students took the teacher's suggestion and thought as the teacher had shown them. In this particular way, metacognitive control was commonly involved in students' argument construction, particularly in the stage of framing claims. Ms. Bowen did not provide scaffolds related to metacognitive control in the other activities. This might explain why metacognitive control was rarely discerned in the other activities.

To sum up, examining the diversity of Mc-A's involvement in various argumentative practices suggests that (1) the knowledge aspect of Mc-A was involved in and related to students' thinking and doing in all these different forms of argumentation; (2) the argumentative dialogue with the characteristics of immediate and explicit responses involved not only students' McK-A but also metacognitive monitoring of their own comprehension; and (3) compared with McK-A and metacognitive monitoring, students' metacognitive control of their thinking and learning might be significantly dependent on teacher's instructional scaffolds at the elementary school level.

6.1.3 Complexity of the Involvement of Students' Mc-A in Argumentation

The results of the data analyses suggest that students had some similar Mc-A, such as knowing the need for consensus. However, how they applied the Mc-A in the practices of argumentation was different. Take the knowledge aspect, for example. Many examples illustrated that students regulated their thinking and doing with their McK-A while they were engaged in argumentation. McK-A about persuasion and the need for evidence was applied consistently. However, there were also examples that showed that students did not apply McK-A during argumentation practices even if they knew it. As shown in examples #13 and #14, David and Ivan articulated similar knowledge about how to resolve differences during argumentative dialogue. In their actual problem solving, David applied that knowledge and led his group to resolve their differences through discussion with evidence; however, Ivan did not. With the available data, it cannot be known whether Ivan did not retrieve that knowledge (i.e., knowledge about how to resolve differences through argumentative dialogue) or whether he deliberately decided not to apply it. These examples demonstrate that the involvement of Mc-A in students' argumentation was complex.

The results of the data analysis also suggest that students had different metacognitive knowledge about argumentation (McK-A), which affected their argumentation practices. Students were aware of the necessity for and importance of evidence; however, their understanding of good evidence varied. Some students thought that having a lot of evidence was good and some thought having too much evidence was not effective. In Jeff's argument construction (example #06 in Chapter 5), he didn't offer much evidence based on his Mc-A that he knew "too much evidence is not good"; however, his argument was not convincing to other students based on their own Mc-A which was that more evidence is better. Jeff's Mc-A, particularly his McK-A about evidence and justification, contributed to his construction of an argument that was perceived as "lack[ing] necessary evidence" by others. From these findings, I understand that sometimes students' McK-A is different in some parts of argumentation, and the differences in McK-A among students affects how they construct and evaluate their arguments.

Students' Mc-A develops through argumentation practice. For example, when Jeff hears his peers' evaluation or feedback in the future, he might re-examine and refine his own McK-A. In this case, students' interactions with critique, feedback, and suggestions during argumentation practices will help refine their McK-A. The process of sharing Mc-A is critical here. For example, once Jeff shared his McK-A about evidence, I realized why he deleted his evidence and understood the importance of his Mc-A in his learning. This finding also suggests pedagogical possibilities and the importance of teachers' scaffolding at the metacognitive level to enhance students' thinking and problem solving in science classrooms.

6.2 Research Question #2

The second research question of this study is: How is the manifestation of students' Mc-A related to classroom interactions with their teacher, other students, and the researcher? This question sought to explore possible factors or contextual elements affecting or being related to students' Mc-A.

6.2.1 Students' Mc-A in Interactions with the Teacher

The findings from this study suggest that the manifestation of students' Mc-A is related to the teacher's instructional supports, both argument-focused metacognitive scaffolds and other scaffolds, as discussed below.

Teacher's argument-focused metacognitive scaffolds. It was found that students' Mc-A manifested when their thinking processes were talked about explicitly. In this study, the teacher engaged students in explicit discussions about and reflections on their thinking with argument-focused metacognitive scaffolds. For example, with *questioning & prompting*, the teacher asked students "What could be your thinking process of preparing the pitch?" Then students started to express what they knew about the goal of their argument construction and the importance of evidence. In this way, within the teacher-led conversation, students talked about their thinking processes explicitly and demonstrated their Mc-A.

According to what students shared during the interviews, the teacher's argument-focused metacognitive scaffolds helped them know and apply their Mc-A. During the interviews, when students were asked how they thought about their Mc-A, they usually attributed it to the teacher's classroom instruction, in which the teacher's argument-focused metacognitive scaffolds were integrated. Students reported that they knew their knowledge about argumentation because they had talked about it in the teacher-led discussion. They also shared that they knew how to adjust their thinking and monitor their own comprehension because the teacher had shown them. The teacher's argument-focused metacognitive scaffolds were recognized and appreciated by the students.

In addition to what students shared during the interviews, the researcher's classroom observations supported the influence of the teacher's argument-focused metacognitive scaffolds on students' Mc-A. It was found that, during the first focused activity, the teacher's argument-focused metacognitive scaffolds were different between the start-up stage and the later justifying stage. At the start-up stage, the teacher provided clear and firm scaffolds. With the teacher's scaffolds, the class discussed *the* goal of argument construction, *the* way of thinking to frame claims, and why they need evidence. However, when they came to the justifying stage, the teacher's scaffolds around such things as what "good evidence" is, how to find good evidence, and how to justify claims were more open ended. For example, the teacher did not confirm any students' criteria of good evidence nor introduce *the* way to find good evidence or justify claims of good evidence. This difference in the teacher's scaffolds might help explain to some extent why students in this study shared the same or similar McK-A about the goal of argument construction and the necessity and importance of evidence, yet diverse McK-A about what good evidence is and strategies for finding good evidence. How the argument-focused metacognitive scaffolds were implemented, either in a firm way or an open-ended way, might affect whether students had similar or diverse McK-A. With this finding as evidence, the importance and influence of the teacher's argument-focused metacognitive scaffolds could be further supported. This finding also raises new questions regarding how argument-focused metacognitive scaffolds should be implemented, which requires future research to explore.

Teacher's other instructional supports. Besides the argument-focused metacognition scaffolds, the teacher's other instructional supports, such as how the learning activities were designed and implemented, also influenced students' Mc-A. Take the first focused activity, for example. Ms. Bowen built a scenario in which students were all NASA innovative technologists aiming to get their technologies approved and supported by NASA. This scenario was helpful for the students to easily accept the goal of argumentation as persuasion and to have an awareness of audience, which was important for their practices of argumentation. In addition, as shown in the example of students' metatalk, it was the teacher's interventions reminding students of the social norms of argumentation that helped the metatalk emerge and develop, which led students to express and refine their McK-A.

6.2.2 Students' Mc-A in Interactions with Peers

The findings of this study also suggest that social interactions between students themselves were also related to the manifestation of their Mc-A, especially the knowledge aspect. In this study, students' argumentative dialogues about argumentation, namely metatalks, were discerned. Within these argumentative dialogues, students could not only express their own McK-A and realize that their peers might have different McK-A from their own, but also refine their McK-A through exchanging and discussing their diverse McK-As. This finding suggests that social interactions are critical for students' learning. Moreover, it suggests that metacognitive knowledge, as a kind of knowledge, is socially constructed in nature.

In addition to the metatalk, in which students explicitly discussed their Mc-A, their social interactions within group work also related to their Mc-A. Findings from this study suggest that students could refine their McK-A in a new learning context by reflecting on their task performances and examining the new context. In this study, these reflections and examinations were discerned mainly in the group problem-solving context. When students embarked on a new learning task which had different requirements and expectations from the previous one, through reflecting on why their new task did or did not work well, students were able to realize that their existing McK-A was or was not applicable in the new context. Then, they would either maintain their McK-A or, through examining the new context closely, update their McK-A. With the maintained or refined McK-A being involved, they could complete the new task. Students' reflections on their task performances and examination of the new context could also facilitate the transfer of their metacognitive monitoring into a new context. For example, through examining a new learning context, such as characteristics of groupmates, students could realize that "they need to be focused," thus they would deliberately apply the self-questioning strategy they had previously learned to monitor their comprehension of their peers' ideas. In this way, metacognitive monitoring could be transferred into a new context and initiated by students themselves, instead of being reminded by the teacher. These episodes, which indicate that students could refine their McK-A and transfer their metacognitive monitoring in the group problem-solving context, are encouraging for educators, because they suggest that the fruitfulness of teacher's scaffolds goes beyond the development of students' Mc-A that takes place under the teacher's guidance and support. Students might continually and independently apply and refine their Mc-A in their later learning experiences.

6.2.3 Students' Mc-A in Interactions with the Researcher

Findings of this study also suggest that methods of collecting data on metacognition influenced students' Mc-A. During the interviews, with my probing into students' thinking and/or inviting students to share their thinking with me, students' metacognitive experiences were stimulated and their metacognition was influenced. In this way, the social interactions between students and the researcher also had the potential to influence students' Mc-A.

Interviews with students also revealed that not all the students were able to share or talk about their own thinking processes and Mc-A, and some students could do this only occasionally (i.e., sometimes, they shared or talked about their own thinking processes and Mc-A, while sometimes they could not). Several possible reasons might help explain this. First, they might not be aware of their own thinking, thus could not talk about it. For example, during the interviews, a few students responded to the researcher's questions, such as "What were you thinking at that moment?" and "What are you thinking (right now)?" with "I do know" or "I have no idea." Second, they might be not able to recall their own thinking process, thus could not talk about it either, especially during the SRIs, as students sometimes replied to these questions with "I cannot remember.” Third, they might be not willing to share, thus their replies of “I don’t know” or “I cannot remember” might be refusals to share. This study focused on students’ manifested Mc-A, particularly how the manifested Mc-A was involved in argumentation. Thus, data collected in this may or may not be appropriate to explain the diversity of students’ metacognitive abilities. More research that specifically focuses on this issue might be needed.

In closing, the findings of this study may provide new insights for science educators and instructional designers interested in promoting and supporting student argumentation and metacognition inside science classrooms. The results demonstrate what is possible in science classrooms when appropriate support and sufficient opportunities are given to engage students in argumentative practice to stimulate their metacognitive experience.

6.3 Implications of This Study

In this section, I discuss implications of this study. First, I discuss the implications for theoretically understanding students’ argumentation. Next, implications for science teaching are discussed. Finally, I discuss implications for future research, both methodological considerations and issues that require more research.

6.3.1 Implications for Theoretical Understanding of Argumentation

The findings from this study suggest that students’ argumentation is a complex cognitive endeavour that involves their metacognition. When students are engaged in argumentation, their Mc-A could affect their decision making regarding what and how they think and act. Therefore, this study suggests research on students’ argumentation to take the metacognitive level of argumentation into consideration.

Taking students’ Mc-A into consideration can improve understanding of students’ argument construction. For example, if students (e.g., Jeff in this study) construct an argument with limited evidence to support the claim, this does not necessarily mean that these students lack the capacity to participate in argumentation, or lack awareness that they need to support claims with evidence, or lack the ability to find supportive evidence. Their Mc-A, such as McK-A, might be affecting their decision making regarding why and how they justify with limited evidence. The final products of their argumentation, such as the arguments they construct, might be not "very well developed." However, they might have gone through a sophisticated process, both thinking and doing. Thus, this study suggests research on students' argument construction paying attention to their metacognition.

Regarding students' argument evaluation, this study suggests that students' thinking processes are usually more sophisticated than their written work might indicate. Studies on student argumentation usually take students' written responses as the main data source to explore students' argument evaluation (e.g., Kuhn et al, 2013; Ryu & Sandoval, 2012). As shown in this study, only examining students' written responses to the argument evaluation task could not fully explain the complexity of students' thinking processes. For example, during the process of evaluating various arguments, in addition to examining the correctness of the claims, students might also have examined the evidence cited in arguments and justification. However, what they wrote down on their worksheets might be only about what they thought about the correctness of the claims. Some examples discerned in this study suggest that students tend to limit their written replies to the correctness of claims. Therefore, in this case, examining only students' written products was not the most effective way to examine their argument evaluation. Moreover, even if some students only examined the correctness of claims while they were evaluating various arguments, as shown in this study, their thinking processes behind those examinations might be not simple. Therefore, it requires more considerations whether examining claims alone is the indicator of lower competency of argument evaluation (Kuhn et al., 2013).

Taking students' Mc-A into consideration in this study also provided valuable information to better understand students' argumentative dialogues. For example, as shown in example #09 in Chapter 5, Jayraj decided to change his initial idea and accept Nate's idea after the argumentative dialogue within their group. That is, conceptual change took place in his knowledge schema. My SRI with him provided information about how his conceptual change took place through argumentation. After Nate provided his evidence, Jayraj did not accept it immediately. Jayraj knew that was his first time hearing Nate's evidence, thus he was not sure whether it was valid. Then, after Nate further explained the source of his evidence, which was thought by Jayraj as reliable, Jayraj decided to accept Nate's evidence and the entire idea. These essential pieces of information, which are critical to understanding how students examine each other's evidence during their argumentative dialogues could not be gained only through observation and/or examination of the final products of their argumentation.

Therefore, this study suggests that attempts to explore students' argumentation should pay reasonable attention to students' Mc-A. Students' observable behaviours during argumentation and/or their (written or spoken) products of argumentation are important, yet might be not sufficient to fully understand students' argumentation. Only focusing on them (i.e., observable behaviours and/or final products) might even lead to misunderstanding students' argumentation (e.g., underestimating students' abilities related to participating in and learning through argumentation). Examining students' Mc-A could help researchers and educators understand and develop students' argumentation more comprehensively in order to support students' critical thinking and problem solving in science classrooms.

In addition, the findings from this study also support that student argumentation can be considered as a form of social practice (Kim & Roth, 2014; Ryu and Sandoval, 2012) that need not and should not be reduced to individual knowledge or skills. Results from this research and previous studies (e.g., Kim, 2016; Kim & Roth, 2014) suggest that argumentative dialogue takes places and develops through social interactions between/among students who hold different ideas. Argument construction and evaluation are social practice as well, even if they are sometimes presented as individual tasks, such as in this study. They are social in nature because when students are engaging in these kinds of argumentative practice, they have, and are influenced by, an awareness of their audience (Chen, 2011), or awareness of being an audience. Moreover, this study found that, not only how students performed argumentation on the cognitive level was influenced by interactions with the teacher and other students (Kim, 2016; Kim & Pegg, 2019; Ryu & Sandoval, 2012), but also the metacognitive level of argumentation. Findings around students' Mc-A have shown that the classroom interactions with the teacher and peers affected students' Mc-A, both the knowledge and regulation aspects. In other words, students' Mc-A is also socially mediated in nature. Thus, seeing from this cognitive-metacognitive perspective, argumentation is a social practice.

These two perspectives—that argumentation is a kind of cognitive activity and also a form of social practice—together help us understand argumentation more holistically and comprehensively than either perspective alone. Therefore, this research suggests understanding student scientific argumentation as a form of social practice and, simultaneously, a complicated cognitive process involving students' Mc-A. Addressing argumentation with this theoretical basis has the potential to bring forward new ideas around developing student argumentation in science classrooms.

6.3.2 Implications for Science Teaching

Through exploring fifth-/sixth-graders' argumentative practice, this study provides important implications to support students' scientific argumentation and metacognition in elementary science classrooms. Through reviewing related literature, Ryu and Sandoval (2012) argued that students' difficulties around scientific argumentation "are well documented" (p. 492). According to them, students often fail to provide evidence for their own claims and demand evidence from others; similarly, students routinely fail to rebut and appropriately warrant the relation between evidence and claim. These difficulties have also been confirmed by other research in the literature (e.g., Bell & Linn, 2000; Jiménez-Aleixandre et al., 2000; McNeill et al., 2006). In addition, some other studies (e.g., Berland & Reiser 2009; Kuhn et al., 2000) have reported difficulties for students to change or revise their ideas. However, this study found that, affected by their Mc-A, students tended to search and provide evidence to support their own claims and demand and examine evidence from others, and they were willing to shift or revise their ideas in light of examining others' evidence, such as when they realized that their peers had provided convincing evidence and they were convinced. In this way, with their Mc-A involved, students engaged in scientific argumentation and learned science through argumentation. These findings support the importance of Mc-A to scientific argumentation and science learning in general and also suggest instructional emphasis on student' Mc-A.

In this study, argument-focused metacognitive scaffolds were integrated into classroom science teaching and learning and found to be helpful for students' Mc-A. Through questioning and prompting students' thinking and modelling how she and other people (e.g., scientists and engineers) think, the teacher engaged students in conscious thinking and explicit discussions about their thinking processes related to argumentation. According to what students shared during the interviews, they learned and knew Mc-A with their teacher's scaffolds. Specifically, they related and attributed their understandings of the goals and norms of argumentation to their teacher's scaffolds. Ryu and Sandoval (2012) and Sampson et al. (2011) have argued that students' lack of understanding the goals and norms of scientific argumentation is the main reason for the limited success or even failure of various instructional supports to improve argumentation. Therefore, in terms of how to support students' Mc-A, particularly how to facilitate students to understand the goals and norms of scientific argumentation in elementary science, this study provides important insights which suggest that adopting argument-focused metacognitive scaffolds in classroom instruction could be a fruitful. McNeill et al. (2016) report that teachers have difficulty determining appropriate instructional supports to help improve students' reasoning or justification. Regarding this, the finding of this study suggest that adopting argument-focused metacognitive scaffolds could be a way to engage students in reasoning, which "can be the most difficult structural component or aspect of argumentation for teachers to integrate into their classroom practice" (McNeill et al., 2016, p. 265).

There are various specific scaffolds teachers could employ in their own classrooms, besides *questioning & prompting* and *modelling thinking*, which were adopted in this study by the teacher participant. It is critical that teachers encourage students to engage in explicit discussion about and reflections on their thinking during argumentation. Scaffolds being explicit is important. In addition to the findings of this study, other research (e.g., Gray & Rogan-Klyve, 2018) supports and emphasizes the importance of scaffolds being explicit on the meta-level. Moreover, these scaffolds should be followed by sufficient opportunities for students to practice. This is because argumentation is also a form of social practice, and should be learned through participating in it. In addition, this study suggests that argumentative practice should not be isolated as special tasks. Rather, argumentative practice should be embedded throughout the entire science inquiry, with the teachers' argument-focused metacognitive scaffolds integrated through the argumentative practice, whenever students need and as teachers think appropriate.

6.3.3 Implications for Future Research

Approaching argumentation from the aforementioned theoretical perspective, this study explored new methods to examine students' argumentative practices, such as using interviews to access students' Mc-A. These methods provided informative data to frame and support the study's findings. These findings raise questions and issues that require more research to help educators and researchers better understand students' argumentation. This section begins with a discussion of the methodological attempts in this study, followed by identification of issues that require more research.

Methodological considerations. To better understand students' argumentative practices, this study suggests taking Mc-A into consideration. Regarding the methodological decision to investigate students' Mc-A, this study suggests that interviews are a feasible method. SRI and in-class informal interviews were employed in this study to gather relevant data about students' Mc-A. Studies on metacognition adopt these methods (i.e., SRI and in-class informal interview) as "retrospective assessment" (p. 83) and "concurrent assessment" (p. 80) of students' metacognition (Veenman, 2005). Few, if any, studies have employed these kinds of interviews to understand students' argumentation. These interviews provided me informative data as both SRI and the in-class informal interviews afforded me opportunities to learn students' inner thinking processes and rationales behind their observable actions and interactions.

Together with the confirmation that these interviews could be helpful techniques to learn student argumentation, other noteworthy issues about these interviews were also revealed. The first is that both of these two kinds of interviews are not neutral data collection methods. For example, as described in the Findings chapter, my questions during the SRIs influenced students' Mc-A. This finding echoes what Thomas (2012) explains, that "conducting any research into metacognition (which involves seeking data from research subjects) is itself a form of intervention that has the potential to provide a metacognitive experience for the student" (p. 137). Moreover, both of these two kinds of interviews are self-report data collection. Thus, like other self-report data collection methods, what students shared during the interviews about their thinking processes (either after or during the task) might be not exactly the same as how they actually thought (Veenman, 2005). I acknowledge this as one of the limitations of this study regarding data collection. Future researchers who want to use these methods to learn student argumentation, particularly Mc-A, will need to be aware of and keep these issues in their minds as they design their research. Regarding employing interviews to gather data on students' Mc-A, this study has another suggestion for future researchers; that is: building a trust-based relationship with the students is critical for collecting informative data with these self-report interviews, in which "the level of information revealed in controlled by the group members being investigated" (Merriam, 2016, p. 145).

Scholars in the field of metacognition argue that the presence of metacognition, which is an inner mental awareness or process, cannot be directly observed but only inferred (White, 1998, as cited in Thomas, 2012). In this research, however, the manifestation of students' Mc-A was observed directly as well as being inferred. The observed manifestation of students' Mc-A mainly took place within the classroom conversations between students and the teacher or their peers, in which students' thinking processes were talked about explicitly. Therefore, this study suggests that observation could also be a method to investigate students' Mc-A.

Issues that require future research. Students' experiences, rather than the teacher's, were the focus of this study. Thus, in this study, the teacher's experiences were not explored. What kinds of challenges did the teacher participant in this study encounter? What difficulties might other teachers face when they try to introduce argument-focused metacognitive scaffolds into their own classrooms? What kinds of supports might teachers need before they implement these scaffolds? More research focusing on teachers would be beneficial to including this kind of scaffolding into science classrooms to facilitate student argumentation.

In this study, the teacher participant employed two kinds of argument-focused metacognitive scaffolds (i.e., *questioning* & *prompting*, and *modelling thinking*) and other scaffolds as well. Students in this study appreciated the teacher's scaffolds and attributed their Mc-A to these scaffolds. Therefore, this study would argue that these scaffolds positively affected students' Mc-A and their argumentation, thus, were effective. However, it cannot be concluded that a particular pedagogy, such as adopting these two scaffolds, is *the most* effective way to promote student argumentation or metacognition. To understand the effect of the argument-focused metacognitive scaffolds on student argumentation and metacognition, future research, perhaps with different specific scaffolds, remains much needed. Moreover, it is conjectured, based on the findings from this study, that how the argument-focused metacognitive scaffolds were implemented, either in a firm way or an open-ended way, might affect whether students had similar or diverse McK-A. Therefore, there is a need for future studies to continue to explore how the implementation of teacher's scaffolds is related to student argumentation.

It was found in this study that some students could transfer their McR-A, particularly metacognitive monitoring, and refine their McK-A in a new learning context. However, due to the research design of this case study, such as there was only one argument evaluation task and one argument construction activity, findings from this study might be not very sufficient to draw conclusion about the adaptation of students' Mc-A. Therefore, more future research is needed to continue to explore how students adapt their Mc-A when engaging in either familiar or unfamiliar contexts.

6.4 Other Considerations Regarding This Research

Several things related to this study require further consideration. These things are discussed in this sections to allow readers to gauge the usefulness and appropriateness of the findings for other settings. The first thing is derived from the methodological decision. This study was framed as a qualitative case study. Due to the nature of qualitative research, only one class was included in this study. Additionally, no control group was included in this study with which to compare the results and interpretations. However, even without a large number of participants or control groups, rich and detailed descriptions of the research site, participants, and findings might help readers make decisions about the study's application to other settings.

The second thing involves the selection of students participating in SRIs and semistructured interviews. Through reflecting on the process of interviewee sampling, I noticed and acknowledged the bias in my purposive sampling. To gather informative data, students invited for interviews usually were the ones who had active classroom participation and verbal interactions with their teacher and peers. This bias might result in quiet students being underrepresented in my research, which I see as definitely a limitation of this study. Moreover, it is noteworthy that, with these criteria (i.e., having active classroom participation and verbal interactions with their teacher and peers), students who participated in the interviews were all boys (as shown in Table 3.2 Information about the student interviews). There was a girl (i.e., Nadia) who wanted to join in the second round of the SRI and semistructured interviews. But because of a timing conflict, I did not have the chance to interview her formally even though I had some in-class informal interviews with her. The gender composition of the class might help explain why all interviews were done with boys. Among the 19 students in this class, 15 of them were boys. All the students, except 1 boy, were willing to participate in this study. Thus, I had 14 male students and 4 female students as participants. Moreover, compared with the boys, all these 4 girls were quiet and didn't want to participate in interviews (Nadia later agreed to participate in interview, yet did not make it due to the time conflicting). For these reasons, there was a gender inequality in the data collected, especially the data from the SRIs and semistructured interviews. I also acknowledge this gender inequality in the data as a limitation of this study.

Moreover, because this research was about metacognition, which is an inner mental awareness or process, my own inference was involved in data interpretation. In addition, data about students' metacognition were mainly from their self-report interviews. Therefore, all the findings related to students' Mc-A were generated with my inference being involved and based on the assumption that what students shared and reported about their thinking was exactly the same as how they actually thought during their argumentative practice.

6.5 Final Remarks

I started the journey of my research by pondering how we, as human beings, might prepare ourselves in this highly and increasingly science-/technology-influenced post-truth era, and what essential things we could and should teach our kids in schools to support their future citizenship. I was quite worried about these issues. Motivated by an eagerness to understand these concerns and holding my worries about the future deep inside, I decided to pursue issues around argumentation and metacognition. Specifically, I decided to explore students' argumentation, with the focus on not only their doing but also their thinking and their thinking about thinking, that is, their metacognition in the context of argumentation (Mc-A).

It is difficult to explore people's thinking, and even more difficult to explore their thinking about thinking. This is because people's inner thinking usually cannot be observed directly, thus people's self-report is necessary. However, not all people have the ability to recall their and/or the vocabulary to describe it. Compared with adults, it might be more difficult for young children, such as the elementary students in this study, to recall and share their thinking and their thinking about thinking. Another difficulty comes from how to interpret students' Mc-A. Like any other researchers on metacognition, I also employed my inference throughout the data interpretation. What degree of inference is acceptable? To what extent can I infer to distinguish the metacognitive part from the cognitive, when the two are usually, if not always, intertwined? These questions are the most challenging part during the entire research.

Even if this study has been challenging, I have gained greatly. Along the long journey of my research, my fears and worries about the future have gradually disappeared. Every moment when I heard "What is your evidence?", "How can you make sure that is reliable?", "I think I need to change my way of thinking", etc., in the elementary classroom, I knew that students' abilities to think critically and learn independently were developing, and they are getting ready for the ever-changing society. As my journey continues, I become more and more positive about and hopeful for the future world, future education, and our future generations, as a citizen, an educator, and a researcher. I have also become more and more confident about the meaningfulness of my work. At the same time, I feel more responsibility as a researcher in the field of education. The research furthers my path as a researcher and a human being. As I walk the path, I am going on to explore new possibilities to understand and support children's learning and development.

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Appendixes

Appendix A: Example Questions for Student Interviews

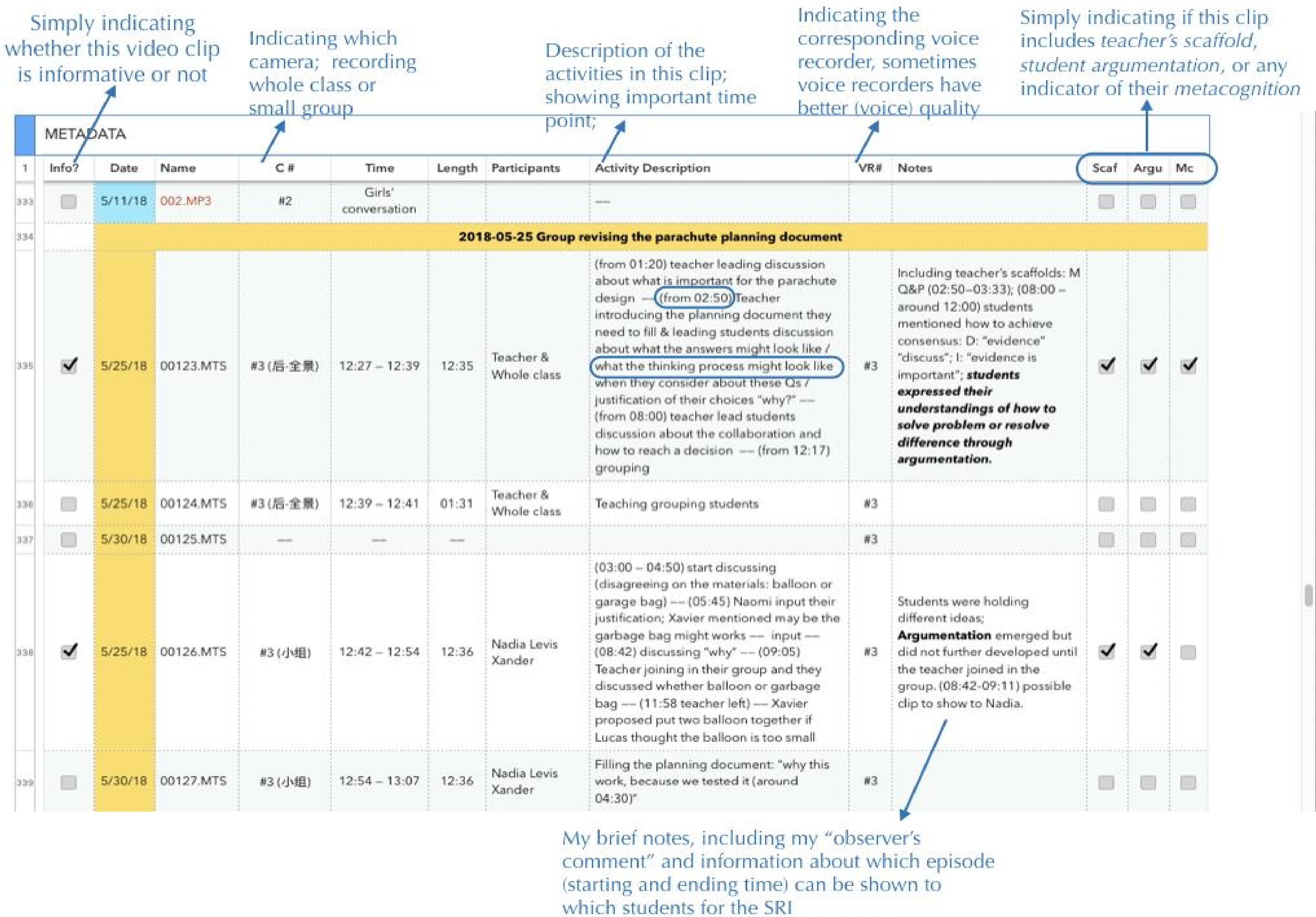
Stimulated Recall Interview (SRI) *(After student(s) reviewed the chosen video episodes)*

<table>
<tr><th></th><th>Examples of Questions</th><th>Purpose</th></tr>
<tr><td>1</td><td>I noticed in the video clip that you. . .. What were you thinking just then?</td><td rowspan="2">- To access students' rationales behind certain behaviours or arguments
- To access students' Mc-A.</td></tr>
<tr><td>2</td><td>Would you like to share with me how you thought (or your thinking process) when you. . .?</td></tr>
</table>

Semistructured Interview

<table>
<tr><th></th><th>Examples of Questions</th><th>Purpose</th></tr>
<tr><td>1</td><td>I noticed in this science class that you sometimes participate in argumentative practice. Do you think participating in argumentation helps you understand a concept? If so, how does it help?</td><td>- To externalize students' perceptions of the function of argumentation in their science learning</td></tr>
<tr><td>2</td><td>I noticed that in science class your teacher always reminds you to question yourself about whether you fully understand what other people say or what happens, how you get your ideas, and if you are convinced by others. Do you always follow the teacher's suggestions?</td><td>- To prepare for the next question</td></tr>
<tr><td>3</td><td>Do you think that kind of self-questioning is helpful to your participation in the classroom discussion or your science learning? If so, how does it help?</td><td rowspan="2">- To externalize students' perceptions of the function and role of the argument-focused metacognitive scaffolds, questioning and prompting on students' thinking, and teacher modelling thinking process, respectively</td></tr>
<tr><td>4</td><td>I noticed that sometimes your teacher showed you how she thought, for example, when she needed to prepare her pitch. Do you think your teacher's sharing of her own thinking process is helpful for your thinking? If so, how does it help?</td></tr>
</table>

Appendix B: Screenshot Showing a Part of the Video Log and the Explanatory Notes



1	Info?	Date	Name	C #	Time	Length	Participants	Activity Description	VR#	Notes	Scaf	Argu	Mc
333	☐	5/11/18	002.MP3	#2	Girls' conversation			—			☐	☐	☐
334		**2018-05-25 Group revising the parachute planning document**											
335	✓	5/25/18	00123.MTS	#3 (后-全景)	12:27 – 12:39	12:35	Teacher & Whole class	(from 01:20) teacher leading discussion about what is important for the parachute design — (from 02:50) Teacher introducing the planning document they need to fill & leading students discussion about what the answers might look like / what the thinking process might look like when they consider about these Qs / justification of their choices "why?" — (from 08:00) teacher lead students discussion about the collaboration and how to reach a decision — (from 12:17) grouping	#3	Including teacher's scaffolds: M Q&P (02:50–03:33); (08:00 – around 12:00) students mentioned how to achieve consensus: D: "evidence" "discuss"; I: "evidence is important"; ***students expressed their understandings of how to solve problem or resolve difference through argumentation.***	✓	✓	✓
336	☐	5/25/18	00124.MTS	#3 (后-全景)	12:39 – 12:41	01:31	Teacher & Whole class	Teaching grouping students	#3		☐	☐	☐
337	☐	5/30/18	00125.MTS	—	—	—			#3		☐	☐	☐
338	✓	5/25/18	00126.MTS	#3 (小组)	12:42 – 12:54	12:36	Nadia Levis Xander	(03:00 – 04:50) start discussing (disagreeing on the materials: balloon or garage bag) — (05:45) Naomi input their justification; Xavier mentioned may be the garbage bag might works — input — (08:42) discussing "why" — (09:05) Teacher joining in their group and they discussed whether balloon or garbage bag — (11:58 teacher left) — Xavier proposed put two balloon together if Lucas thought the balloon is too small	#3	Students were holding different ideas; **Argumentation** emerged but did not further developed until the teacher joined in the group. (08:42-09:11) possible clip to show to Nadia.	✓	✓	☐
339	☐	5/30/18	00127.MTS	#3 (小组)	12:54 – 13:07	12:36	Nadia Levis Xander	Filling the planning document: "why this work, because we tested it (around 04:30)"	#3		☐	☐	☐

Appendix C: Materials for the Teacher-Participant

Appendix C-1: Examples of Teacher Modelling

Here is an example reported in a recent study (Yilmaz, Cakiroglu, Ertepinar, & Erduran, 2017) showing a teacher who was modelling constructing arguments to his students.

Please note that this is only an example. It does not mean this is what the practice (i.e., teacher modelling) should look like. Teacher modelling in practice has various representations.

Mesut (a science teacher), in his science lesson, modelled constructing arguments to his students:

> *"Here, in the second part, there are three friends, statements and some claims related to the observations of the three buddies who went to race. You will try to show whether claims are right or wrong. If it is right, why is it right? If it is wrong, why is it wrong?... **Hasan, for example, agrees with Can's claim. He will say that 'I agree with Can's claim because of this or that...' or 'this also supports my claim because...'.** First, we will do this in groups and then we will discuss altogether. "*

In this episode, Mesut did not share with his students his own thinking process of constructing arguments. But, he did simulate how Hasan would think if he/she had a claim. Through modelling on Hasan's argument constructing, Mesut showed his students the causal structure of arguments.

Besides Mesut's words in the above example, what follows are also some examples of teacher modelling thinking process in classrooms. You might consider adopting them in your science teaching whenever you think appropriate. Again, they are only examples. You definitely can and are encouraged to frame your own phrases.

- *"I know that to support my ideas I'd better find some evidence, so now I am searching through what I already know to find the evidence."*
- *"Based on the evidence, I think that. . .."*

- *“Here is my claim. . . supported by the evidence. . ..”*
- *“We know that the evidence cited should be related to the claims. But in this argument, the cited data is irrelevant to the claim, so I will not accept it.”*
- *“I know that the discussion between us is to achieve a conclusion on which we all agree. So, I won’t take others’ refuting as a personal attack. Now that I know they do not agree with my idea, I will ask them for reasons.”*

When you think your students are getting more knowledgeable about argumentation and more capable of regulating their thinking during argumentation, you can consider the following way of modelling thinking process:

- *“Before I knew these norms of argumentation . . . I only focused on the correctness of the conclusions. Now I know that . . . so I pay attention to and think about the relationship between the evidence and the conclusion and the validity of evidence. Knowing these norms changes my way of thinking.”*

Appendix C-2: Examples of Questioning and Prompting

Here is an example from the study of Yilmaz and his colleagues (Yilmaz et al., 2017), showing a teacher who was trying to facilitate his students' argumentation in a science classroom through questioning.

Please note that this is only an example. It does not mean this is what the practice (i.e., questioning and promoting) should look like. Questioning and promoting to facilitate metacognition in practice have various representations.

In this episode, through posing those two questions, the teacher was trying to remind his students to focus on *how they thought* when they chose the evidence, and emphasize the importance of *justification* in argumentation.

Ahmet, in his first teaching practice, asked students to use evidence cards to support their arguments. The topic of argumentation was the transfer of heat. He provided the students with an activity, which required them to use their knowledge on the transfer of heat to decide which floor (1st, 2nd, or 3rd) of the given three apartments (Apartment A, B, and C) would be most suitable to live in winter. In the following script, Ahmet questioned the validity and relevance of the evidences of the students to check whether they have a base:

Teacher: *7, 8 and 10 (referring to evidence cards).* ***How do these support your arguments?*** [QUESTIONING]

Student: *We thought convection would be more useful for us. Here it generally mentions convection. For example, heat goes from the warm to the cold matter. In the convection, warm air and cold air takes each other's place and the heat may be transferred from hot weather to cold weather.* [ARGUMENT]

Teacher: ***How is it related to the apartment example?*** [QUESTIONING]

Student: *Because there is convection in the apartment. Eight says that sun gives heat by radiation. Sun gives heat by radiation here too. Ten says warm air rises up. This is convection, so it supports.* [ARGUMENT]

Teacher: *Well, for A-2 you say supported by ten. When we look at the shape of the apartment, where is the warmed air?* [QUESTIONING]

Student: Here (shows by finger)

Besides the way of questioning in the above example, what follows are some other examples of questioning and prompting in the classroom. You might consider adopting them in your science teaching whenever you think appropriate to further support students' thinking. Again, they are only examples. You definitely can and are encouraged to frame your own phrases.

To encourage students to fully express their ideas:

- "How did you get that idea?"
- "How do you know?"

To encourage students to consider issues from both sides or an alternative side:

- "Can you think of an argument against your view?"

To promote the thinking of "listeners":

- "Does this idea make sense to you?"
- "Do you fully understand this?"
- "Are you convinced? Why?"
- "If so, why?"
- "If not, think about what you can do."

When you think your students are getting more knowledgeable about argumentation and more capable of being aware of and regulating their thinking during argumentation, you can consider asking questions like the following:

- "Yesterday we talked about information, data, and evidence, and how we think with them. Are you thinking differently about the way you use information now to make a point?"
- "Last lesson, we discussed the norms and goals of argumentation (or discussion). After learning these norms or goals, are you thinking differently now when you try to make a point (or construct your argument)?"

Appendix D: Transcripts of Classroom Episodes and the Researcher's Analysis Notes

Appendix D-1: Classroom Episode #01_The Persuasive Goal of Argument Construction

Line #		**Transcript of the Classroom Conversation** (Classroom recoding transcript, 2018/03/14)	**Analysis Notes** (i.e., My Interpretation)
01	Teacher:	… You might have known NASA. Last week, we learned planets and their moons, we watched some videos from NASA. Today, we will first learn NASA's three major missions …	
02		[*Students watched videos from YouTube introducing NASA's Mars exploration, Hubble Space Telescope, and the International Space Station.*]	Teacher used videos to engage students

NASA at Mars: 20 years of 24/7 exploration

https://www.youtube.com/watch?v=JXZa8cmab1g

NASA's Documentary Film: Hubble25 (Abbreviated Version)

https://www.youtube.com/watch?v=UZI23PBOv5o

The International Space Station: Together is the Future

https://www.youtube.com/watch?v=NtrVwX1ncqk&frags=pl%2Cwn

03	Teacher:	Anyone can provide us a brief summary of each technology project and how that technology benefit us?	
04	Levi:	Mars, it helps us to know how Mars is, kind of, made, and understand if you could somehow move there.	
05	Kelvin:	Hubble telescope. Help us discover new places and provide us a large amount of knowledge of the space.	
06	Ivan:	International Space Station was launched by Russian rocket in 1998, the International Space Station was made, because, to get to do experiments to see what it's like in space, look what we can do, or can you make an enter artificial flight that you can make without air, there is no air there.	
07	Teacher:	Thank you for that summary of those three very important technologies. Today we will be getting our journey to work, creating our own technology. Each one of you as innovative member of the tech design team will be creating your own technology for NASA. Now, let me introduce myself and other two adults in the room to you to welcome all you innovative technologists to NASA. I am the manager of Mars Project, Ms. Peters, the manager of the Hubble Telescope, and Qingna is the director of the International Space Station. We and all your colleagues will be in the panel to evaluate your technology and determine whether NASA will support your design. Creating your own technology for NASA, that will have some type of objectives that we need to meet in order to expand our understanding. So, before we going to the specifics of that I would like to show you a video that has been put out by NASA that promotes the development of technology. This video, I just want to play it to inspire your thoughts and to give you a good understanding of why the work we're doing is very important. So, I will play that now and then we will continue our conversation about creating our own individual	Teacher built the scenario for the NASA technology design project and introduced this activity Teacher played a video to engage students Teacher explicitly shared with the students why she used this video: to let students to know what they were going to do was important

		technology.	
08		[*Students watching the video from YouTube.*]  EXPLORATION - Inspirational NASA Space Film Introduction of this video (published on Aug 1, 2015) from the creator: *"EXPLORATION is an inspirational piece reconnecting history with the present … showcasing the passion and drive man has always had to touch the stars. …"* https://www.youtube.com/watch?v=xAuxvVBMykI	
09	Teacher:	So, this video is just showing you some information about why space exploration is important why humans have chosen to begin their investigation and continue their investigation in space…	
10		[*Teacher and students had some conversation about the content of the video, as one students said he saw in this video the Earth was destroyed.*]	
11	Teacher:	Now, we are moving to the next portion of our time here today, which is discussing what is the important objective of creating your pitch. As the NASA innovative technologists, if you want to introduce your most important development or your opinion, so it is according to you what would be the most important thing to pursue at this point, what do you think is your purpose? And what is your way of thinking to achieve this purpose? Just imagine how would the innovative technologists think in this situation?	Guide students to think the goal of this project/assignment with *questioning & prompting*
12	Levi:	So, basically, it's the, kind of, discussing something in a way to prove that yours could be a good idea.	
13	Teacher:	Yes! It might be a good word 'prove'. You might want to prove that yours is a great idea. Then, your way of thinking might be thinking, ok, how can I prove it, right? … So, you want to think of	*questioning & prompting*

		something that you think could be pursued, and at the same time, would be helpful in space technology and beneficial to NASA and the entire human beings.	
		Maybe, let us think of a few examples, so just off the top of my head, for example somebody might target food and space, so I want to look at that kitchen and I think this needs to be developed, whatever it is, maybe it's a cooking utensil maybe it's a particular food item, so your space technology might be the food the astronauts eat. Then, you might think how can I prove that my idea, creating or improving the food astronauts eat, is great, and think how can I persuade NASA to support my design.	Teacher gave two examples, with those examples the teacher modelled how students would think through teacher modelling (*modelling thinking*)
		Another person might say, actually, I think we need to get ourselves to Mars, like you're attempting to do so, I think I would develop this. Or, actually, forget Mars, let us go to another planet. Then, you also need to think, like, think in the same way, how can you prove that your idea, getting people to other planets, is great, right? So, you might have different things you want to pursue, but the way of thinking to develop the project is quite similar here.	Explicit discussion/introduction the *thinking process* of designing their technologies
14	Levi:	So, basically, create something that would be helpful to space technology and persuade, like persuade other people what, like, what you think would make it for.	Students realized and explicitly talked about the persuasive goal of argument construction
15	David:	Yes, like, think how to be persuasive, think how to prove and persuade NASA that mine is unique and they should support it.	Student described his way of thinking
16	Teacher:	Absolutely! You're proving your idea, you are pitching it actually. If you are in a company and you have something to pitch. What will you do? How do you think to make the pitch? You probably think that you need to convince the management or whoever it is why your idea is great. So, your assignment then will be to represent this, so you're going to think about how you could represent this, and how you can convince us, your colleagues, other technologists in NASA, right? Now, you know that you need to be persuasive and to be convincing, right?	*questioning & prompting* *modelling thinking*

17		[*Students agreed and said "yes."*]	
18	Teacher:	We are now moving to the last part of today's science [class], let us think about what specific, what are the criteria for a good pitch. So, what things are you going to have to demonstrate for me, the head of the tech department, to ensure that your technology is something that could be implemented effectively into space exploration. We have to meet certain objectives to get there, right? So, what I would like to do today is splitting us off into groups and brainstorm some ideas in a small group about what criteria, what specifications are going to be necessary for us to accurately create our piece of technology? What are you going to have to show me and the other technologies in the room for your technology to be approved? Does anybody have any questions about what you're going to be discussing in your small groups?	Teacher organized students to brainstorm the criteria of this project
19	Levi:	We discussed with the pieces that we want to have?	Students expressed confusions
20	Teacher:	You are discussing overarching criteria. We have co-constructed criteria in the past, so it's basically the question what does this assignment need from you, what would make it a strong assignment. Any questions? After we brainstorm the criteria that needs to be met, then you'll have the opportunity to think more individually about the piece of technology you're creating and plan that out.	Teacher connected back to their previous learning experiences to explain what students were supposed to do
21		[*Students were assigned into groups brainstorming the criteria of this project. Teacher joined each group. Then, they had a wrap-up whole-class discussion, students shared what they had discussed about the criteria such as "making your work clear," "need a plan," "using illustration" etc.*]	

Appendix D-2: Classroom Episode #02_Framing Claims "Both Innovative and Realistic"

Line #		**Transcript of the Classroom Conversation** (Classroom recoding transcript, 2018/03/16)	**Analysis Notes** (i.e., My Interpretation)
01	Teacher:	Welcome back to NASA! Today we will continue our technology design journey. We talked about some criteria that we want to meet to make our projects very strong, such as we need to make it clear. Now, let us listen to a colleague from NASA, let us see what are their criteria. So, now I am showing you another video. In this video, you will also see some technologies they are working on right now, such as the robots, astronauts' suits, radiation shielding and so on. That will give you some clue on what you want to design.	Teacher connected back to their previous class and used the YouTube video to further introduce the criteria for this technology design project (i.e., the technology should be both innovative and realistic) Teacher explicitly shared with students the purpose of this video
02		[*Students watching the video from YouTube.*]  NASA 360 Presents - From Science Fiction to Science Fact Introduction of this video (published on Oct 28, 2014) *"NASA's Innovative Advanced Concepts (NIAC) … nurtures visionary ideas that could transform future NASA missions with the creation of breakthroughs — radically better or entirely new aerospace concepts — while engaging America's innovators and entrepreneurs as partners in the journey…"* https://www.youtube.com/watch?v=1cXrpSdcTEg	This video was very helpful introducing "both innovative and realistic" technologies and some possible directions students could think, such as robots, astronauts' suits, life-support in space etc. Many students reported in the interviews and later classes that got their ideas from this video
03	Teacher:	As we see in this video, NASA requires our design, our proposal to be both innovative and realistic, also can expand our knowledge about the space. [*Levi raised his hand.*] Levi?	Teacher emphasized the new criteria: "both innovative and realistic," and also could expand the knowledge about space
04	Levi:	What do you mean with 'realistic technology'? Are	Students expressed

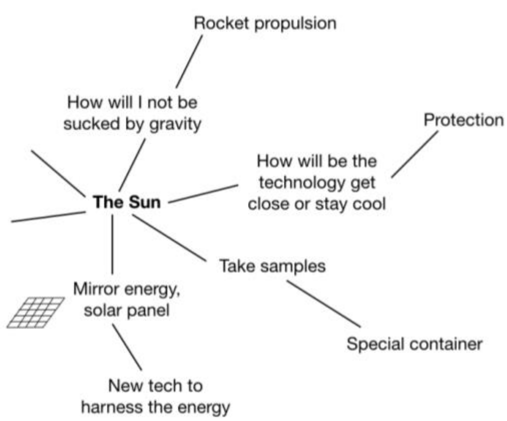
		not we inventing some imaginary technology?	concerns about "both innovative and realistic"
05	Teacher:	What do you think? [*Asking the class*] Are these scientists or technologists in NASA just making up these technologies, thinking, like, how can I make up invention? Are these inventions only from imagination? How do you think they made these innovations? [*David raised his hand*] David?	Teacher encourage students to think how scientists think
06	David:	Maybe, like, they are educated, like, they are scientists.	
07	Teacher:	Yes! They are educated, that means they know a lot in their areas, right? [*Students nodding*] So, they think innovative ideas based on their knowledge, what they have known. [*Students nodding*] Then, how do you think we can make our technology design both innovative and, at the same time, realistic? How could we do, how could we think? Remember, we are not designing something randomly. [*Ivan and other students raises their hands*] Ivan?	Teacher explained how scientists think through *modelling thinking* *questioning & prompting*
08	Ivan:	We learned about our technology first? But [*he stopped*]	
09	Teacher:	How do you think we work in this way, like we use information from reliable sources to support our design? Do you think this will make our design both innovative and also realistic? [*Nate, Levi and other students raised their hands*] Nate? Then Levi?	
10	Nate:	How can be find reliable sources for the innovation? It is innovation, it is new.	
11	Levi:	What are the reliable sources, since we are working on some make-up technologies? What would you mean with reliable sources?	
12	Teacher:	[*Speaking to the whole class*] Their concerns remind me that we have talked about that your design is not random, you are not thinking to make up your technology, you are thinking to make something based on what you have already known. Does innovation need to be something completely new? It	*questioning & prompting*

		must be something that no one has heard before? [*students said "no."*] Let us think, let's think cars. Are people, scientists and engineers still design new cars? We already had cars. Do you think the new cars are innovations or not? [*students said "yes"*] I am paralleling this to cars, because I am thinking why people are still designing new cars?	The teacher explicitly shared with students her thinking process
13	Ivan:	To try to make it faster, because the car did not ran very fast.	
14	David:	More efficient with gas, and some are use electricity now, like, the Tesla.	
15	Teacher:	Yes! So, innovation does not have to be something completely new, right? If you are improving something, that is innovation for sure! If you are adding something to it to make it, like, more efficient, more, that is also innovation, or you can delete or get rid of some parts that were no longer necessary, these changes are also innovations. Of course, you can create or invent something, it is innovation for sure, but you also can improve it. Right? [*Students nodding*] So, try to think like that, first, think about what interests you, and then, think about how we can find what we have already known about it, what we talked about, what you have learned about. Then, based on your personal interest and the knowledge you know, you will have your topic, and you will also make your technology both innovative and realistic. Then, you explain how your technology is benefitting NASA and entire human being. In this way, your argument will be very strong.	Teacher emphasized what 'being innovative' meant Teacher introduced the way of thinking to generate their claims with *questioning & prompting*
16	David:	So, basically, we need to think like, first, what interest me, for example, the moon Europa, and then, think, what knowledge maybe NASA has known about it, is this the way?	Students talked about the way of thinking to frame their claims
17	Teacher:	Yes, exactly, that could be your way of thinking to generate your topics or technologies, and frame your claims. Everyone clear? [*students are nodding*]	

		What we're going to do next is going over, giving you some context of what has been happening in the present time in space technology development and where NASA is looking to go in the future. Some of their projects that they are hoping to put make a reality by the year 2050. We're going to watch another video that talk about the to-do-list from NASA and some of the exploration that they would like to do and technologies they want to create to achieve the exploration, to give you some inspiration.	Teacher explicitly shared with students the purpose of watching this video
18		[*Students watching the video from YouTube.*]  NASA's 2018 To Do List https://www.youtube.com/watch?v=CxguTV-xwiI *In this video, NASA's to do list includes:* *1. Send a robot to Mars* *2. Launch astronauts with American companies from U.S. soil* *3. Visit an asteroid as old as our solar system* *4. Search for planet around distant stars* *5. Embark on a journey to the Sun* *6. Fly closer (to the sun) than ever before* *7. Prepare to send humans to the Moon and beyond and bring them back home* *8. Prepare to launch the next great observatory* *9. Live and work in space for the 18th consecutive year* *10. Partner with companies on deep space habitats* *11. Monitor our dynamic Earth* *12. Track the Earth's water from the space* *13. Use space lasers to measure ice on Earth* *14. Use space lasers to map forests* *15. Fly an efficient and eco-friendly electric airplane* *16. Partner with industry to make sonic booms quieter* *17. Fire thrusters with eco-friendly propellant* *18. Improve space navigation* *19. Find new ways to harness the Sun's energy*	This video was very helpful for students to think of their technology. Many students also reported in the interviews that got their ideas from this video
19	Teacher:	So, I heard you guys said while we were watching that we've done some of those things. Why would it	Teacher noticed some students were still confused to some extent

		still be on the to do list?	with what she explained about ‘innovation’ or ‘being innovative’. Thus, the teacher led students to discuss it again
20	Nate:	Maybe send more people to the Moon and send more people to the Mars?	
21	Teacher:	Why would that be something that they would want to do?	
22	David:	To, like, expand what we have done.	
23	Teacher:	Right! To expanding what we have studied was the reason why it would still be on the to do list	
24	Kelvin:	To improve it.	
25	Teacher:	Exactly, to make new improvement. So, sending new technologists that can do different and more, and different things, right? and explore different aspects. So, that's why some of those, like sending humans to the moon, still be on that list. It's only happened once and they still have a lot to learn from about the moon and having more human visitors would be beneficial. Again, this is also about what we talked about what innovation is, it does not have to be something completely new. Right?	Teacher further explained what ‘innovation’ and ‘being innovative’ meant, emphasizing that innovation does not have to be something completely new
26	Teacher (and students):	Now, let us, think and work together at an example. For example, if I am interested in the Sun. [*The teacher was writing on a piece of paper on the projector, so while she was writing and drawing on the paper, the students could see what she wrote and drew from the whiteboard.*] what do you think I can explore. [*student said: “how to escape from the gravity”*] yes, how will I not be sucked by gravity [*while the teacher was speaking she wrote it down on the paper*], so what do I need? [*student said something cannot hear clearly*], yes, I might need the rocket propulsion. What else, what other aspects related to the Sun I can explore? [*student said: “how you can get close but not be melt?”*] so, how will be the technology get close and stay cool, then what do I need? I need to do some research on such	Teacher invited students to work together on an example to show them how to generate the idea

		as give me spaceship some protection, that could be my design right? What else? [*student said: "taking samples?"*] Yes, exactly, take samples, so I might design a special container to keep the samples. What else? [*student said: "solar energy"*] Yes! I could mirror and gather the solar energy with solar panels, I am drawing a solar panel here, so my technology could be design new technology to harness the solar energy. So if I am interested in Sun, I have these different aspects that I can think of. Then, after I decide which direction I want to pursue I will do more research on that to learn more about that. You try to also think and work in this way to generate your idea, ok? [*students said "Yes"*]	



What the teacher wrote and drew (researcher's field notes)

27	Teacher:	So, now we are moving into the individual planning and researching stage. [*Teacher gave students a handout.*] You will think of a design, just like the Sun we did. And this is a draft version of what your technology is. It may be something we want to add to it or change about it, as we switching as we go through, remember, it does not need to be completely new. You will have your Chromebook, and you are answering and completing this planning documents with these three questions [*teacher pointing the handout*]. First, what are the objective of your technology? Second, why is your piece of technology valuable to space exploration? Third, why should NASA consider funding your technology over other designs? What makes it	Teacher introduced the handout and led students to started framing their claims

	worthwhile? So, you will need to think a realistic and also very innovative technology, which you will need to persuade us that it should be approved and supported by NASA. That is your claim. So, basically, claim is your statement, your answer, your opinion about, like a question. In this situation, the question is 'whether NASA should approve and support your design?' Right? So, what could be your statement, your answer to this question? Your answer is your claim. So, 'your technology, your innovative design should be supported by NASA' is your claim. Anyone has questions about what claim is? [*students did not have any questions.*] When you do the planning, you also need to do the researching, the researching is helping your planning. You have an idea, let us say that is your personal interest, you think how to connect that with the space, this is the innovative part, right? Then, you might think to start your research, you find what people have already known about this topic, how you can improve it or make it better. Of course, you can think something new. There's a large variety of sources we can use. We can use websites, we can use books, we can contact experts. So those are just some examples of things that you could possibly do. As your research goes, you will have more and more information about your topic, then you might want to change your original one, that is totally fine, that is great actually, this is how scientists and technologists work, right? Everyone clear with what we are going to do? [*students nodding*]	Teacher introduced students what claim is Teacher showed how scientists work and think through *modelling thinking*
28	[*Students worked individually with their Chromebook and the planning document. Teacher sometimes talked with students individually.*]	

Appendix D-3: Classroom Episode #03_Importance of Evidence

Line #		Transcript of the Classroom Conversation (Classroom recoding transcript, 2018/03/21)	Analysis Notes (i.e., My Interpretation)
01	Teacher:	… Now, you all have your own technology that you want to present to NASA. Remember that we have decided to do an actual pitch, so what does that mean? What is a pitch of something?	Teacher emphasized the goal of argument construction through asking them questions
02	David:	A pitch proposal is to tell people, like, this is what my product is, and why it is unique and like, important.	
03	Teacher:	Yeah! A couple words I am taking away from that is you said what and why, what it is and why it's important. Does anyone have anything to add with what is a pitch?	
04	Nate:	To prove and persuade NASA that your technology is contributing to the space exploration.	Students mentioned "to persuade" was the goal
05	Teacher:	Yes, exactly, to persuade! The goal of the pitch is to persuade NASA to approve and support your technology. That is your claim, right? Like, smoothies for the astronaut, the rovers to explore outer space, whatever your technology is, 'your technology should be approved and supported' is your claim. Doing a pitch is to support your claims and make your arguments very strong. The pitch, the entire pitch, we also call it 'argument'. It includes your claim and how and what you are going to use to support to prove your claim. The entire thing we call it an argument. We are trying to make our arguments very strong, right? Then, what could be your thinking process of preparing the pitch, making your argument very strong?	Teacher confirmed students' idea and further emphasized "the goal … is to persuade" Teacher reminded students what 'claim' is and introduced 'argument' *questioning & prompting* on students' thinking process
06	Kelvin:	Like, you need to think about how to be persuasive, like, with lots of helpful information.	
07	Teacher:	Information! For sure! Ultimately your pitch, your argument is going to convince the panel, like as Kelvin said, with all the helpful information you have, which is your evidence. Evidence is very important, actually the most critical part in your pitch.	Teacher introduced and emphasized the necessity and importance of evidence

		Then, how will you know your writing, your argument is convincing?	
08	Levi:	Usually, in convincing writing, you usually put all the positive sides of your technology, like the reasons why my idea is great, more reasons is better than less [*cannot hear clearly*]	Students mentioned the sufficiency of evidence
09	Zhao:	Yes, like put all you have, all the evidence you can find, all the helpful information, that is helpful	
10	Teacher:	Yeah, more reasons, like sufficient reasons, right? Sufficient evidence to prove your technology is good. It is important for sure! How about, let's take Kelvin's for example, my ideas [developing smoothies for astronauts] is great, because I love smoothies, persuading? What you think? [*Students were all laughing*]	Asking students questions to guide students to think about the quality of evidence
11	Levi:	You can decide to research on smoothies because you love it, but it cannot be used as like evidence. Because, it is not good evidence.	
12	Teacher:	Then, what is good evidence in your mind?	
13	Nate:	Good evidence can be from research, something from experts and books, and research.	Students mentioned what "good evidence" is
14	Ivan:	Good [evidence], like, is what we learned from classes.	
15	David:	Not necessarily to be from classes, but good evidence needs to be true … and make sense to other people.	
16	Teacher:	Make sense to other people, that is important. You do not want to talk about something that no one can really understand, right? You want your audience to know it. This reminds me, like, when we prepare ours or listen to others', try to think, like "will this make sense to other people?" "does this make sense to me?" Like David said make sense to the audience to the panel to whoever you are presenting to is important. Anyone has anything to add about evidence? [*no student raised their hand*]	Teacher encouraged students to monitor their thinking while they were constructing their own arguments or evaluating others' arguments *questioning & prompting*
17	Teacher:	… we have decided to do an actual pitch for the technologies you have designed, whatever it is, we need to persuade NASA that your idea is great with	Teacher showed students her own

		sufficient and also good evidence. For example, if I am doing my pitch, I will first think about a topic that really interest me and use sufficient and good evidence to prove and persuade other people that my technology is good for pursue. When I am doing it, I will also think questions like "is my argument convincing?" "do I have enough evidence?" "is my evidence really good and from reliable sources?" and "does it make sense to other people, my evidence and my explanation?" all the time. This my way of thinking of preparing my pitch, developing my argument.	thinking process of constructing her argument and how she would monitor her thinking through *modelling thinking*; also emphasized the necessity and importance of evidence
18	Teacher:	We have another ten minutes, I want you to think about your own claims and how to support it with evidence, think about what kind of evidence you can use to make your argument strong. We will continue the NASA project after our spring break …	

Appendix D-4: Classroom Episode #04_Group Sharing and Giving Each Other Feedback

Line #		**Transcript of the Classroom Conversation** (Classroom recoding transcript, 2018/04/09)	**Analysis Notes** (i.e., My Interpretation)
01	Teacher:	… Ok, how about we start from David. Everyone else, you can either close your Chromebook return it, and will focus on helping David, ok? People get ready? [students nodding and saying 'yes'] So, David, tell us about where you're at right now.	Teacher organized the four students for their group sharing
02	David:	where I'm at right now? I only have one slide, so, what else to write to make it better, like why should NASA buy it? what I'll do is talk, like, [he started to read his slide] my rover comes with built in laser drill, 360 wheels that are hovering under the rover. To withstand Europa's harsh winds my rover has a countermeasure. When the wind gets to a high enough level, the rover deploys four hooked. Steel ropes that bury themselves in the ice on the moon, then the 360 wheels attach electromagnetically to the bottom of the rover.	
03	Teacher:	Thank you, David, that is very informative, you must have done lots of research. So, I am wondering why Europa? Why NASA should spend money on Europa?	Teacher asked a question
04	David:	Eh, that is, it is because Europa is, like, very important.	Student's simple answer
05	Teacher:	Ok, so are you guys [talking to other three students], thinking you are the NASA people, are you convinced by David's presentation? What do you think he can further improve it to make his work stronger?	Teacher invited students to give their suggestions
06	Jayraj:	[Speaking to David] You can introduce more about why Europa?	Student repeated the teacher's question
07	Teacher:	[Speaking to Jayraj] Why do you think that would be helpful to make his pitch strong?	Teacher tried to further students' thinking
08	Jayraj:	That helps to persuade, like, you say, it is good and you also need it.	Student furthered his thinking and explained
09	Teacher:	David, do you think Jayraj's suggestion is helpful?	Teacher connected students' ideas together
10	David:	Yeah, like, I need to persuade NASA to buy my	

		technology, so, like, basically, he [Jayraj] is saying that I need to prove that, like, they need it.	
11	Teacher:	[Asking David] You need to buy my technology, because it is very good. Is this persuading?	
12	David:	Eh…	
13	Teacher:	What do you think [asking other students]? You need to buy my technology, because it is good, it has so many functions. Or, let us rephrase it, do you think the 'so many functions' are really related, really relevant to the decision of buying it? Is this persuading?	The teacher tried to further students' thinking with an example
14	David:	No? [rising tune] you do not *buy* [he emphasized the word in italics] all the good things, like, you buy it because you need [he emphasized this word] it. oh, I know, I know, I need to prove that NASA *needs* [emphasized] it, NASA *needs* [emphasized] to explore Europa.	
15	Teacher:	Exactly! That is the way people in NASA, or our audience, think, right? Remember, we have audience, we try to think how they would think to make their decision, right? They will think, like, David's design is very good, and we also need his technology, then, we will definitely buy it, right? The 'it is good' part is important, but, like, provide more information about why they need it, what your technology can bring them etc., that will make all your evidence more relevant to your claim. [asking other students] Any ideas? Any other suggestions for David? Levi?	Teacher modelled how to think from the perspective of audience (*modelling thinking*)
16	Levi:	Like, your technology is, has lots of parts, very innovative. Then, how are you gonna send it to Europa?	
17	Teacher:	Oh, Levi mentioned the "both innovative and realistic" that we have discussed. [asking Levi] so you are asking him about his realistic part, are you?	Teacher connected back to what they discussed in previous class
18	Levi:	Yes.	
19	David:	I will send it with a rocket [he is opening his information sheet] I do have some, I saw some from	

		NASA [he is looking his information sheet] they have a rocket, I can use to send my rover to Europa.	
20	Teacher:	That is very good, so you might consider including that part into your presentation too.	
21	David:	I don’t want to say this is the best rover in the universe. I want give some facts to prove that it is good.	
22	Teacher:	Yes, exactly! I am glad that you mentioned this, we cannot just say, like, my technology is good, very good, we need to prove it, right, using evidence, facts, like David said. Then, what are you hoping for the feedback from us at this point? Or you need some work time?	Teacher emphasized the importance of evidence
23	David:	I want some time to work [he is going to leave]	
24	Teacher:	David, could you please stay and listen to others, because they have supported you, right? [David stay] So, Nate, what do you want from us?	
25	Nate:	Communication, I want to know how my robots on other planets can communicate with the Earth …	
26	Teacher:	Do you guys have any ideas or suggestions for Nate?	Teacher organized student to discuss; when the discussion among students went well and was productive, the teacher did not intervene
27	Levi:	You can use, maybe, X-ray.	
28	Jayraj:	Yes, X-ray, or like radio waves.	
29	Nate:	Yeah, but like it [using X-ray or radio waves] will take a long time.	
30	David:	Yes, it will take decades to get there.	
31	Levi:	No, it will not. When I sent an email, almost literally across the world, it gets there in a couple seconds.	
32	David:	No, it does not.	
33	Jayraj:	Yes, it does for me. I had exactly the same [experience].	
34	Nate:	That [sending and receiving emails in seconds] is because there are satellites to receive and transfer your information, but there is no satellite in the space.	
35	Jayraj:	Really?	
36	David:	Yes, exactly.	

37	Nate:	Yes, I did my research on this, so I want to know whether you have any good ideas.	
38	Jayraj:	Oh. [nodding]	
39	Levi:	Oh, yes. Then you might want to distinguish whether the information you want to send back to the Earth is emergency or not …	

Appendix D-5: Classroom Episode #05_ "We Are Going to Have Our Presentations"

Line #		**Transcript of the Classroom Conversation** (Classroom recoding transcript, 2018/04/13)	**Analysis Notes** (i.e., My Interpretation)
01	Teacher:	Welcome back to NASA! Finally, we are going to have our presentations today. As we have said, we will first share our technologies, you present your work to the panel, telling us why NASA should approve your technology, right? Then, you will have some questions from the panel as well. Anything concerns you about our presentation?	
02	Levi:	It need to be aware that we need to limit the questions. In small groups, if it has lots of questions [that is fine]. If presenting to the whole class, it will take a lot of time.	
03	Teacher:	Yes! I will keep an eye on that, thank you! We cannot ask questions forever. So, how do you think we can handle that, for example, in a real presentation, an actual pitch in a company, if there are lots of questions, how will you work around that?	
04	Levi:	Kind of combine certain questions that have one answer, that kind of combining.	
05	Teacher:	Yes, sometimes we can combine questions.	
06	David:	Probably, start with or use the most important questions.	
07	Teacher:	When you said the 'most important', that reminds me 'prioritizing'. When you have questions, you need to be aware that what is on the top level. [*saying to the whole class*] Their concerns remind me that, do you think asking and answering the questions are important? [*students were nodding*] Why? Why do you thinking asking questions is important? Why we are doing this?	Teacher led the class to discuss the importance and purposes of Q&A
08	Jayraj:	To know more, like, if he forgot saying something.	
09	Teacher:	Yes, asking for some details, of course. What else? Why it is important?	

10	Adam:	It is communicating. Like if something you cannot understand, so I can explain it.	
11	Zhao:	I can let you know if, like, you are wrong.	
12	Teacher:	But we are not criticizing, right? We are helping each other to improve our work, to make it stronger. How can we ask good questions to help each other? What could be your thinking process of asking a good question?	Teacher emphasized the purpose of asking each other questions Teacher asked students how they can ask good questions (*questioning & prompting*)
13	Ivan:	You need to focus and listen carefully.	
14	Zhao:	Yes, like, very pay attention.	
15	Teacher:	Yes, exactly! Pay attention to what the presenter is say. Maybe you could think 'do I understand this?' while you are listening to the presentation. Like, later, when you present your technology, I will think 'do I understand his words?' 'he says, he is going to send off his robots in this way, does this make sense? Is there any better ways to do this?' I will pay more attention on the part whether your evidence is supporting your claim, like, I won't judge your design is, for example, good-looking or not. Or, your design is bad, you design smoothies for the astronauts, I do not like smoothies. [*students laugh*] But I care more about, hey, what is your evidence to prove that your technology is important? If you are designing smoothies, show me why it is important for NASA, right? Try to think like this while we are listening, like, try to monitor whether you are understanding or not. Asking ourselves, "do I understand?" "what is the evidence?" "is the evidence supporting?" Then, we will have very good questions to help your peers. [*students nodding*] Any other advice for others and ourselves to make a strong pitch, because we are going to do it? Any advice?	*questioning & prompting* Teacher modelled her own thinking process of listening to the presentations as an audience (*modelling thinking*) Teacher encouraged students to monitor their own thinking
16	Henry:	Be persuasive.	

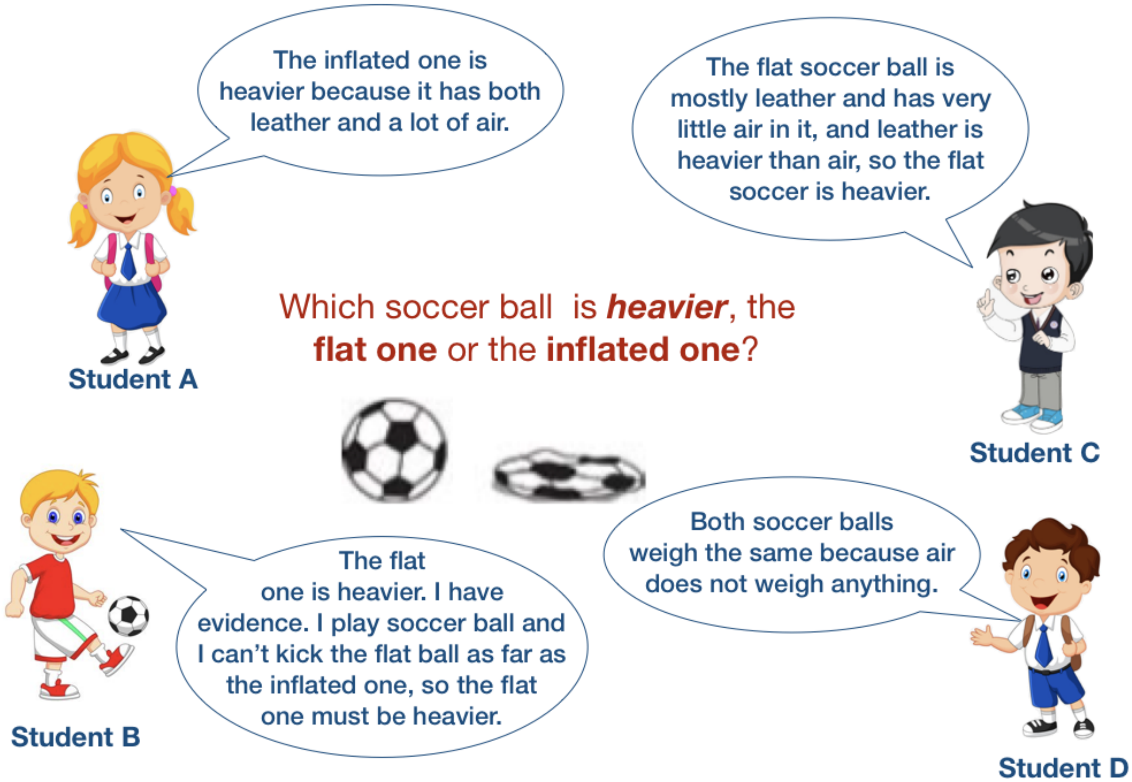
17	Teacher:	And how do you know you will be persuasive?	
18	Henry:	Be aware of the words you are using.	
19	Jeff:	Do not be nervous.	
20	Teacher:	We know, it is interesting to know that it is normal to be nervous, so how can we deal with those emotions?	
21	Jeff:	My mom told me, like, do not look at the people.	
22	David:	No, but we need eye contact … [*cannot hear clearly*]	
23	Kenny:	Just see it as another practice.	
24	Teacher:	Yes, we talked and we practiced, and it is just another sharing of our work, isn't it? [*Teacher organized students to started their presentations*]	

Appendix D-6: Classroom Episode #06_ "How Should We Think During the Collaboration?"

Line #		Transcript of the Classroom Conversation (Classroom recoding transcript, 2018/05/25)	Analysis Notes (i.e., My Interpretation)
01	Teacher:	… We know that usually when we work as groups, sometimes, we have different ideas, so how do you think we can reach the agreement? What is a good way of collaborate with peers? How should we think during the collaboration? For example, he wants to use garbage bag [to make the canopy], but you like to use for example the paper. Scientists also need to think about this too, right?	Teacher led students to discuss how to dissolve difference during their collaboration through *questioning & prompting*
02	Jeff:	We can vote.	
03	Teacher:	Vote, do you think voting is a good way to solve the problems? Do scientists always vote? [*Jayraj said something, but cannot hear clearly.*] Yes, we share evidence and discuss, we discuss which option might be better or the best. Be respectful … [*cannot hear clearly*] this is how scientists think and do too. Like, this is your conclusion, then show your evidence as well, right? … with evidence, they communicate, this is how knowledge develops too …	Teacher drew students' attention to the evidence-based decision making through modelling how scientists think, communicate and work (*modelling thinking*)
04	David:	Like, everyone in the group should have the chance to express, like say this is what I think, and this is my evidence … and we, as a team, compare the evidence, and make our decision, like, what, how big it is.	Students mentioned evidence
05	Ivan:	… we can discuss … we can take the turn to say our ideas, and we talk about it … yes, and you have to give your reasons … discussion can solve [the disagreement], because reasons and evidence are always important.	Students mentioned evidence
06	Teacher:	Yes, exactly, evidence and reasons are always important, right? We communicate with evidence and respectfully just like how scientists do and think. [*Students got their Chromebook and started to work as small groups.*]	Teacher confirmed key ideas

Appendix E: Argument Evaluation Task

Argument Evaluation Task _ Part-01



- **Which student's argument do you think is the most convincing? And why?**

I think Student ____ is the most convincing.

Because____

____

____

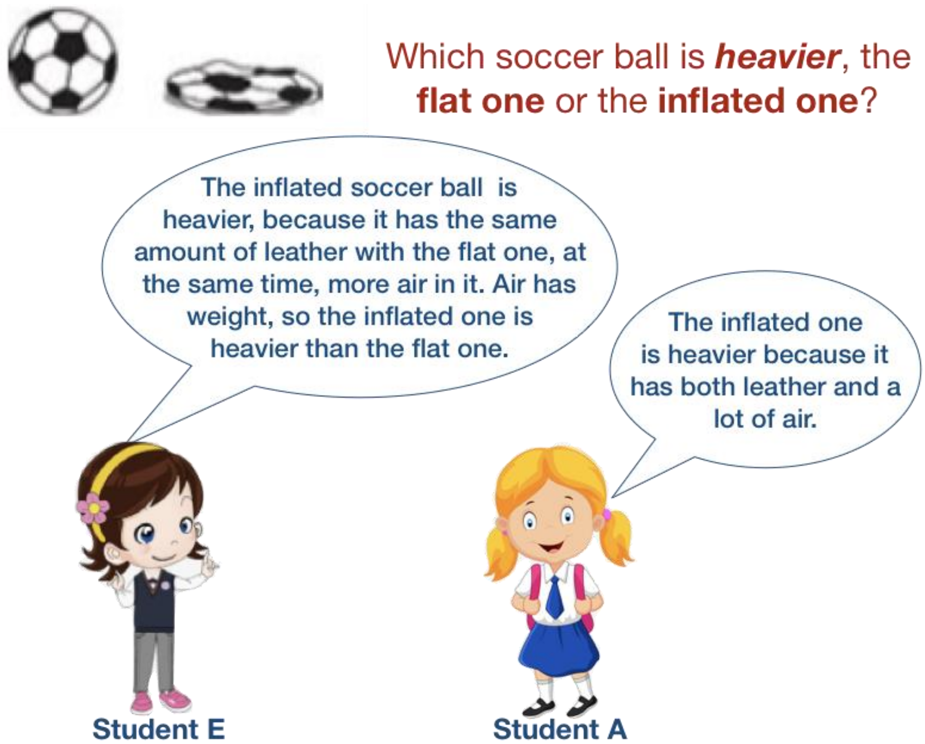
- **Try to describe the thinking process of how you made this choice.**

____

____

____

Argument Evaluation Task _ Part-02



Student E shared the same point of view with Student A. She further developed her argument as shown above.

- **Whose argument/statement do you think is stronger or more convincing? why?**

- **Try to describe the thinking process of how you made this choice.**

Appendix F: Informed Consent and Assent Letters

Appendix F-1: Information Letter to School Principal

Study Title: Exploring students' metacognition in the context of argumentation in an elementary science classroom

Research Investigator:
Qingna Jin, Doctoral Student
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Supervisor:
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Background & Purpose

Your school is invited to participate in a study entitled *Exploring students' metacognition in the context of argumentation in an elementary science classroom* being conducted by Qingna Jin, at the Department of Elementary Education, University of Alberta. The study is to explore students' scientific argumentation in the everyday science classroom setting. Scientific argumentation in classroom has been seen as a core practice of getting students to engage in science and as a means of promoting their science learning and making students scientifically literate. Through argumentation, students will learn how to explain and justify their knowledge and decision making. This is one of the fundamental aspects of scientific literacy.

Study Procedures

One of your school science teachers on Grade four to six and his/her classroom students will participate in this project. The researcher and the science teacher will collaborate to develop a feasible framework of classroom discussion and argumentation, which is localized to your school and the teacher's approaches. Some metacognitive scaffolds (e.g., teacher modeling and metacognitive questions and cues) will be introduced into the science classroom to stimulate students' metacognitive experiences. Therefore, the researcher and science teacher will work together to develop viable ways of integrating those scaffolds into his/her classroom science teaching as well.

When the project is implemented in class, students in your school will work in groups to solve scientific and technological challenges and problems, and participate in some metacognitive activities during their science learning. Activities designed in this project (both the problem solving and metacognitive activities) will be part of the regular curriculum and will be conducted during selected teaching periods. Thus, all students in that class will participate in those activities.

The entire research period will be around 20 weeks, covering two to three learning units. Science classes during the research period will be audio/video taped. There is no extra time required to participate in this study, except the science teacher and some students will be invited for interviews. Students will be interviewed individually in the middle and at the end of the research period. Interviews with students are about what and how they think while they are engaged in argumentation, how they understand argumentation, as well as how they perceive the functions of the metacognitive processes, in which they are encouraged to engage. In addition, students' written work from class activities will be collected as data. Students can decide not to participate in data collection process. Please note that there will not be any disadvantage of not participating in this study since all students in the classroom will work on the same tasks and activities.

Classes and interviews will be video/audio taped and students' written work from class activities will be collected as data. These data will be used only for data analysis.

Benefits

Scientific argumentation, highlighting metacognitive reflection in it, will enhance students' scientific and critical thinking, epistemic understanding, as well as logically communicating skill. This study will also introduce strategies of scientific argumentation and metacognition to the science teacher, thus is expected to help the teacher with pedagogical strategies, teaching resources, and reflective practice of science teaching for his or her professional development.

Risk

The study will be conducted during the regular class time so there is no foreseen hard arising from participating in the research other than the presence of the researchers and videotaping in the classroom. Having video cameras around, some students might feel uncomfortable. When children express discomfort toward videotaping, I will not video-record a child and minimize the inconvenience as much as possible.

Voluntary Participation

The participation in this research must be completely voluntary. If a child decides not to participate, no data from the child as a non-participant will be collected. But please understand that the exercises of the study will occur as part of the regular curriculum and the child will still complete the exercises. But they can choose not to participate in data collection process such as video recording and interviews.

Even if the teacher and students agree to participate in this study, they can withdraw from this project at any time. The teacher participant can send an informal written letter, call or email to the researcher, to withdraw from the whole study or certain parts of the study at any time. Children and their parents can also withdraw at any time from the study or any part of the study through sending an informal written letter, call or email to the classroom teacher or the researcher. If students or their parents decide to withdraw, then the students will be considered as non-participants, and continue participating in all the classroom learning activities, but no data from them will be collected thereafter. Concerning data already collected (e.g., interview, classroom recordings and writings), if they agree, the data might be interpreted for the summary of group work in confidential manners. If they insist all their data be removed, then all the data related to the withdrawn students will be destroyed and will not be interpreted or used in any form. If the teacher participant decides to withdraw from the entire study or certain parts of the study, I will discuss with the teacher to see how to revise the research design or, if it is necessary, to stop the whole research in his or her classroom.

After the data collection, you and your students can still discuss your withdrawal with the researcher by sending an informal written letter, call or email to the researcher. But please note that the last point for data withdrawal will be 30 days after the data collection is completed.

Confidentiality & Anonymity

This project is the researcher's doctoral dissertation research. It is anticipated that the results of this study will also be shared in university classes for teacher education purposes, conference presentations and published articles. When I need to show the video data of classroom activities, I will only use the screen shots and will blur the teacher's and students' faces to secure their identification. When I need to show the interview data, pseudonyms will be used to protect participants' anonymities. The teacher's and students' anonymity and confidentiality will be secured during any types of data presentation.

All data is confidential with access restricted to the researcher at the University taking part in the study. The teacher's and students' identity will not be revealed. For confidentiality of both the teacher and students, the video and audio data will be stored in password protected computer files. Written data will be secured in a locked filing cabinet in Qingna Jin's office in the University of Alberta (If I need to move from that office, written data will be move to another locked filing cabinet in Qingna Jin's home, to which only the researcher has the access).

According to the university policy, the data will be kept for a minimum of 5 years following completion of the study. After 5 years, all the password protected files will be permanently deleted and the written data will be shredded.

Further Information

If you have any further questions regarding this study, please do not hesitate to contact Qingna Jin. The contact information is below.

Qingna Jin
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The plan for this study has been reviewed for its adherence to ethical guidelines by a Research Ethics Board at the University of Alberta. For questions regarding participant rights and ethical conduct of research, contact the Research Ethics Office at (780) 492-2615.

Thank you for your consideration.

Sincerely,

Qingna Jin

Appendix F-2: Information Letter and Consent Form to School Teacher

Study Title: Exploring students' metacognition in the context of argumentation in an elementary science classroom

Research Investigator:
Qingna Jin, Doctoral Student
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Supervisor:
Dr. Mijung Kim
Department of Elementary Education
University of Alberta
Edmonton, AB, T6G 2G5
mijung@ualberta.ca
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Background & Purpose

You are invited to participate in a study entitled *Exploring students' metacognition in the context of argumentation in an elementary science classroom* being conducted by Qingna Jin, at the Department of Elementary Education, University of Alberta. The study is to explore students' scientific argumentation in the everyday science classroom setting. Scientific argumentation in classroom has been seen as a core practice of getting students to engage in science and as a means of promoting their science learning and making students scientifically literate. Through argumentation, students will learn how to explain and justify their knowledge and decision making. This is one of the fundamental aspects of scientific literacy.

Study Procedures

The researcher and you as classroom professional will collaborate to develop a feasible framework of classroom discussion and argumentation, which is localized to your school and your approaches. Some metacognitive scaffolds (e.g., teacher modeling and metacognitive questions and cues) will be introduced into your science classroom. Therefore, the researcher will also invite you to work together to develop viable ways of integrating those metacognitive scaffolds into your inquiry based science teaching. When the project is implemented in your class, your students will work in groups to solve scientific and technological challenges and problems, and participate in some metacognitive activities during their science learning. Activities designed in this project (both the problem solving and metacognitive activities) will be part of the regular curriculum and will be conducted during selected teaching periods. Thus, all students in that class will participate in those activities.

The entire research period will be around 20 weeks, covering two to three learning units. Science classes during the research period will be audio/video taped. There is no extra time required to participate in this study, except you and some of your students will be invited for interviews. Students will be interviewed individually in the middle and at the end of the research period. Interviews with students are about what and how they think while they are engaged in argumentation, how they understand argumentation, as well as how they perceive the functions of the metacognitive processes, in which they are encouraged to engage. Interviews with you are about how you feel about teaching with those metacognitive scaffolds and how you perceive your students' work. In addition, students' written work from class activities will be collected as data. Students can decide not to participate in data collection process. Please note that there will not be any disadvantage of not participating in this study since all students in the classroom will work on the same tasks and activities.

Classes and interviews will be video/audio taped and students' written work from class activities will be collected as data. These data will be used only for data analysis.

Benefits

Scientific argumentation, highlighting metacognitive reflection in it, will enhance students' scientific and critical thinking, epistemic understanding, as well as logically communicating skill. This study will also introduce the strategies of scientific argumentation and metacognition to you, thus is expected to help you with pedagogical strategies, teaching resources, and reflective practice of science teaching for your professional development.

Risk

I do not expect any risk to you as a science teacher but there might be emotional stress to you and your students regarding videotaping. The study will be conducted during the regular class time so there is no foreseen hard arising from participating in the research other than the presence of the researcher and videotaping in the classroom. Having video cameras around, you and some students might feel uncomfortable. When discomfort toward videotaping is expressed, I will not video-record you and the children but only audio record and minimize the inconvenience as much as possible.

Voluntary Participation

The participation in this research must be completely voluntary. If a child decides not to participate, no data from the child as a non-participant will be collected. But please understand that the exercises of the study will occur as part of the regular curriculum and the child will still complete the exercises. The researcher will not videotape any non-participant. However, sometimes it is very difficult to do so since children will move around in the classroom to complete their tasks. I will ask you to group non-participants into the same groups to avoid videotaping them. When non-participants move around, they might be videotaped with participants' groups but they will not be shown in any public presentation forms. But if they participate in participants' group discussion, their talk will be used for data interpretation of the group.

Even if you and your students agree to participate in this study, you can withdraw from this project at any time without any negative consequences or penalty. You can send an informal written letter, call or email to the researcher, to withdraw from the whole study or certain parts of the study at any time. Your students and their parents can also withdraw at any time from the study or any parts of the study through sending an informal written letter, call or email to the classroom teacher or the researcher. If students or their parents decide to withdraw, then the students will be considered as non-participants, and continue participating in all the classroom learning activities, but no data from them will be collected thereafter. Concerning data already collected (e.g., interview, classroom recordings and writings), if they agree, the data might be interpreted for the summary of group work in confidential manners. If they insist all their data be removed, then all the data related to the withdrawn students will be destroyed and will not be interpreted or used in any form. If you decide to withdraw from the entire study or certain parts of the study, I will discuss with you to figure out how to revise the research design or, if it is necessary, to stop the whole research in your classroom. After the data collection, you and your students can still discuss your withdrawal with the researcher by sending an informal written letter, call or email to the researcher. But please note that the last point for data withdrawal will be 30 days after the data collection is completed.

Confidentiality & Anonymity

This project is the researcher's doctoral dissertation research. It is anticipated that the results of this study will also be shared in university classes for teacher education purposes, conference presentations and published articles. When I need to show the video data of classroom activities, I will only use the screen shots and will blur your and your students' faces to secure your identification. When I need to show the interview data, pseudonyms will be used to protect participants' anonymities. You and your students' anonymity and confidentiality will be secured during any types of data presentation.

All data is confidential with access restricted to the researcher at the University taking part in the study. You and your students' identity will not be revealed. For confidentiality of you and your students, the video and audio data will be stored in password protected computer files. Written data will be secured in a locked filing cabinet in Qingna Jin's office in the University of Alberta (If I need to move from that office, written data will be move to another locked filing cabinet in Qingna Jin's home, to which only the researcher has the access).

According to the university policy, the data will be kept for a minimum of 5 years following completion of the study. After 5 years, all the password protected files will be permanently deleted and the written data will be shredded.

Further Information

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Qingna Jin
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The plan for this study has been reviewed for its adherence to ethical guidelines by a Research Ethics Board at the University of Alberta. For questions regarding participant rights and ethical conduct of research, contact the Research Ethics Office at (780) 492-2615.

Thank you for your consideration.

Sincerely,

Qingna Jin

Consent form

Your signature below indicates that you understand the above conditions of participation in this study, that you have had the opportunity to have your questions answered by the researcher, and that you consent to participate in this research project.

Please indicate your dis/agreement on video-recording during the research. After you sign the two copies of the consent form and keep one copy for you and return the other copy to the researcher.

I agree to participate in interviews.	Yes No .
I agree to participate in video-recording process during interviews.	Yes No .
I agree to participate in video-recording process during classroom activities.	Yes No .
I agree that video data can be used in the researcher's doctoral dissertation, academic journal publications and workshops, with all the identifying information removed.	Yes No .

I agree to participate in the study described above. I have read and understand the purpose, process, and requirements of the study. Furthermore, I understand that (a) participation is voluntary, (b) I have the right to terminate participation at any time, and (c) I have the right to have collected data treated in a secured and confidential manner.

____________________ ____________________ ____________

Your name Signature Date

Thank you.

Sincerely,

Qingna Jin

Doctoral Student, Science Education
Department of Elementary Education
551 Faculty of Education
University of Alberta
Edmonton, AB, Canada
T6G 2G5

Appendix F-3: Information Letter and Consent Form to Parents and Assent Form to Students

Study Title: Exploring students' metacognition in the context of argumentation in an elementary science classroom

Research Investigator:
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Supervisor:
Dr. Mijung Kim
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(780) 492-0922

Background & Purpose

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Study Procedures

Students will work in groups to solve scientific and technological challenges and problems and participate in some metacognitive activities during their science learning. Activities designed in this project (both the problem solving and metacognitive activities) will be part of the regular curriculum and will be conducted during selected teaching periods. Thus, all students in that class will participate in those activities.

The entire research period will be around 20 weeks, covering two learning units. Science classes during the research period will be audio/video taped. There is no extra time required to participate in this study, except the science teacher and some students will be invited for interviews. Interviews with students are about what and how they think while they are engaged in argumentation, how they understand argumentation, as well as how they perceive the functions of the metacognitive processes, in which they are encouraged to engage. Interviews with students will take place in the middle of and at the end of the research period. You and your child can decide not to participate in data collection process. Please note that there will not be any disadvantage of not participating in this study since all students in the classroom will work on the same tasks and activities.

Classes and interviews will be video/audio taped and students' written work from class activities will be collected as data. These data will be used only for data analysis.

Benefits

Scientific argumentation, highlighting metacognitive reflection in it, will enhance students' scientific and critical thinking, epistemic understanding, as well as logically communicating skill. This study will also introduce strategies of scientific argumentation and metacognition to the science teacher, thus is expected to help the teacher with pedagogical strategies, teaching resources, and reflective practice of science teaching for his or her professional development.

Risk

The study will be conducted during the regular class time so there is no foreseen hard arising from participating in the research other than the presence of the researchers and videotaping in the classroom. Having video cameras around, some students might feel uncomfortable. When you and your child express discomfort toward videotaping, I will not video-record your child and minimize the inconvenience as much as possible.

Voluntary Participation

The participation in this research must be completely voluntary. If you and your child decide not to participate, no data from your child as non-participant will be collected. But please understand that the exercises of the study will occur as part of the regular curriculum and your child will still complete the exercises. The researcher will not videotape any non-participant. However, sometimes it is very difficult to do so since children will move around in the classroom to complete their tasks. I will ask the teacher to group non-participants into the same groups to avoid videotaping them. When non-participants move around, they might be videotaped with participants' groups but they will not be shown in any public presentation forms. But if they participate in participants' group discussion, their talk will be used for data interpretation of the group.

Even if you and your child agree that your child will participate in this study, your child can withdraw from this project at any time during the data collection without any negative consequences or penalty. To withdraw, you send an informal written letter, call or email to the classroom teacher or the researcher. If you and your child decide to withdraw, then your child will be considered as a non-participant, and continue participating in all the classroom learning activities, but no data from your child will be collected thereafter. After the data collection, you and your child can still discuss your child's withdrawal with the researcher by sending an informal written letter, call or email to the researcher. But please note that the last point for data withdrawal will be 30 days after the data collection is completed.

If you and your child decide to withdraw, with your and your child's permissions, the data already collected (e.g., interview, classroom recordings and writings) might be analyzed to interpret the group work. If you insist all your child's data be removed, then all the data related to your child will be destroyed and will not be interpreted or used in any form.

Confidentiality & Anonymity

This project is the researcher's doctoral dissertation research. It is anticipated that the results of this study will also be shared in university classes for teacher education purposes, conference presentations and published articles. When I need to show the video data of classroom activities, I will only use the screen shots and will blur your child's faces to secure your child's identification. When I need to show the interview data, pseudonyms will be used to protect participants' anonymities. Your child's anonymity and confidentiality will be secured during any types of data presentation.

All data is confidential with access restricted to the researcher at the University taking part in the study. Your child's identity will not be revealed. For confidentiality of your child, the video and audio data will be stored in password protected computer files. Written data will be secured in a locked filing cabinet in Qingna Jin's office in the University of Alberta (If I need to move from that office, written data will be move to another locked filing cabinet in Qingna Jin's home, to which only the researcher has the access).

According to the university policy, the data will be kept for a minimum of 5 years following completion of the study. After 5 years, all the password protected files will be permanently deleted and the written data will be shredded.

Further Information

If you have any further questions regarding this study, please do not hesitate to contact Qingna Jin. The contact information is below.

Qingna Jin

Doctoral Student, Science Education
Department of Elementary Education
551 Faculty of Education
University of Alberta
Edmonton, AB, Canada
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Email: qingna@ualberta.ca

The plan for this study has been reviewed for its adherence to ethical guidelines by a Research Ethics Board at the University of Alberta. For questions regarding participant rights and ethical conduct of research, contact the Research Ethics Office at (780) 492-2615.

Thank you for your consideration.

Sincerely,

Qingna Jin

Consent form

Your signature below indicates that you and your child understand the above conditions of participation in this study, that you and your child have had the opportunity to have your questions answered by the researchers and teachers, and that you consent to participate in this research project.

Please indicate your dis/agreement on video-recording during class activities, written work, and interviews. After you sign the two copies of the consent form and keep one copy for you and return the other copy to the teacher.

My child and I agree my child to participate in video-recording process.	Yes No .
My child and I agree that my child's written work from class activities can be collected as data.	Yes No .
My child and I agree my child to participate in interviews when approached by the researcher.	Yes No .
My child and I agree that video data can be used in researcher's doctoral dissertation, academic journal publications and workshops, with all the identifying information removed.	Yes No .

Parent/Guardian: I agree to allow my child to participate in the study described above. I have read and understand the purpose, process, and requirements of the study. Furthermore, I understand that (a) participation is voluntary, (b) both my child and I have the right to terminate participation at any time, and (c) both my child and I have the right to have collected data treated in a secured and confidential manner.

____________________________ __________________ _______________

Parent/Guardian's name Signature Date

Assent form

Student: I agree to participate in the study described above. I have read and understand the purpose, process, and requirements of the study. Furthermore, I understand that (a) participation is voluntary, (b) I have the right to terminate participation at any time, and (c) I have the right to have collected data treated in a secured and confidential manner.

________________________________ ________________ ______________

Child's name Signature Date

Thank you.

Sincerely,

Qingna Jin

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Department of Elementary Education
551 Faculty of Education
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T6G 2G5