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A Diversity of Pathways Through Science Education

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Introduction

ISEC 2020 was intended to be *the* conference for showcasing research and new thinking in science education. Organized once every couple of years by staff from the Natural Sciences and Science Education academic group at the National Institute of Education, Singapore, its opening was initially planned for the middle of 2020 to coincide with the mid-year or summer holidays for local and international audiences. The International Science Education Conference (ISEC) organizing committee expressed high hopes for at least two reasons: (i) STEM education was to assume an equally prominent theme during this conference, and (ii) ISEC-STEM 2020 aspired that its attendees experience fresh insights on current/future trends and needs in these domains arising from 20-20 vision in this auspicious year. As such, the overall conference theme was entitled *The Tango between Science and STEM* to reflect these aforementioned ideas. It was described on the official website as being able to

> reflect a dance the S-T-E-M education researchers are immersed in as they crossover into interdisciplinary research. Tango also encapsulates the synergy between Science and STEM as Science continues to play a prominent role in STEM education. One of the disruptions to science education as a field is the increasing emphasis on integrated STEM education. With science as the discipline that is currently dominant in integrated STEM, it is strategic that we position ISEC 2021 and STEM 2020 as two related conferences. This will encourage scholars from both fields to interact and develop synergies to move the knowledge forward. (from the conference website)

A disruption of immense proportions did indeed occur although not in the way that the organizers had anticipated because the COVID-19 pandemic plunged most of the world including Singapore into disarray soon after the winter of 2019. This global event scuttled our conference planning resulting in ISEC-STEM being delayed for a year to the summer of 2021 as well as being conducted virtually. STEM 2020 was also decoupled from ISEC 2021 due to various considerations by the organizers. These changes were not as bad as was thought, for now the problems of high registration fees as well as long-distance travel woes were overcome at one stroke though not the issue of participating in real-time across very different time zones. The ISEC 2021 conference was nonetheless successful under these very difficult circumstances with 77 papers/symposia presented by researchers and teachers from 17 states/regions. As with previous ISEC, presenters from Singapore occupied the lion's share of presentations. What readers therefore see in this edited book are a sampling of invited authors who had presented at ISEC 2021.

This book is organized into three parts.

1. Part I: Questions and Questioning in Science/STEM Education
2. Part II: Developing Science Teaching and Assessment
3. Part III: History, Philosophy and Sociology of Science/Engineering and Informal Learning

To summarize, Part I features three chapters foregrounding the epistemic practice of student questioning across grade levels. Part II is hugely diverse in its coverage with five chapters describing different aspects of teaching, learning, and assessment from multiple theoretical standpoints while Part III comprises three chapters that also appear to be very diverse but can be seen as takes on the history and/or development of formal and informal learning in science and engineering. The beginning of each part is accompanied by a Commentary written by each of the book editors who were members of the ISEC organizing committee.

We wish to bring to the reader's attention a unique feature of this edited book: At the end of a chapter, each set of authors has written a "Note to Future Colleagues" to describe their aspirations for the state of science/STEM education research in 2050 in the research area reported in their chapter. Collectively, these "Notes" point toward potential directions that science/STEM education research could take to achieve the espoused visions by the middle of the twenty-first century. On this note (pun intended), the editors of this book would like to end this introduction with our own Note to Our Future Colleagues in 2050.

Note to Our Future Colleagues

It is the year 2050. According to authors Christiana Figueres and Tom Rivett-Carnac of the book *The Future We Choose*, if the world worked together and took appropriate actions to avert the climate crisis, we would be on track to warm by no more than 1.5 °C by the year 2100 (Figueres and Rivett-Carnac 2020). Thus, our future looks bright and science/STEM education continues to be an important part of our culture. Here, we present our three predictions made in the 2020s for science/STEM education in 2050.

I. Epistemic Practices of the Future

By 2050, disciplinary boundaries have blurred as most professionals work in interdisciplinary teams to solve the complex real-world problems. Using the language of 2020s, most professionals and experts are trained in one or more of the "traditional disciplines" such as the sciences or humanities and have working knowledge of several other disciplines. Thus, educators and education researchers have progressed from focusing on disciplinary to interdisciplinary epistemic practices. As working in large interdisciplinary teams is the norm of work in 2050, interpersonal or "soft" skills such as collaboration, communication and empathy have become just as important as content knowledge and procedural knowledge. In addition, engagement in epistemic practices has become part of school norm (though schools no longer take the same form as they did in the 2020s). The ability to critique, construct, and discern trustworthy knowledge claims is now essential to everyday living since most people have become content creators as well as content consumers. Since everyone can find a platform to publish their views, some of which are erroneously/intentionally positioned as truths, it has become challenging—yet part of everyday life—for the layperson to discern trustworthy and sound claims from unwarranted ones, including scams. Incidentally, attempts by large-scale social media platforms and governments to curate online information have failed and thus, the onus of fact-checking remains on the individuals.

II. Science Teaching, Learning, and Assessment in the Age of AI

In the coming three decades, science teaching and learning will become both easier and harder. It will seem easier because so much more will be known about the overall principles of how human cognition functions in the service of acquiring valuable knowledge. The main theories or frameworks will have been mapped out regarding how cognition is dependent on one's internal architecture of neurons as well as the body's engagement with its contextual surround. On the other hand, how cognition interacts with other aspects such as the physical body and its observable states known as emotions or affect will have complexified the fine details of how people learn and behave. Besides, schooling will now be augmented by forms of artificial minds or intelligences in a similar manner as how tools of the past (e.g., the abacus, counting rods, log tables, calculators, the Internet) had assisted classroom learning. The nature and target of assessment too will likely change drastically as mentioned in the commentary for Part II. So despite knowing more than ever about how people learn and in possession of unimaginable new technologies, science teachers in the middle of the century will still have their work cut out for them as they facilitate students in much more demanding tasks (i.e., see the above epistemic decision making) compared to previous eras. A teacher's life will probably remain just as demanding rather than easier and the space-age life with robot teachers imagined in the US cartoon *The Jetsons* will not materialize.

III. Schools of the Future

The COVID-19 pandemic was the trigger that kickstarted what will likely be the biggest evolution in schools since the widespread adoption of formal schooling during the first Industrial Revolution, and that 30 years hence, its repercussions continue to shape and redefine what "schools" are. The lockdowns and restrictions imposed certainly advanced the pervasive use of and drove the development of technologies for remote learning and remote work. More significantly, these affordances for and the experience of remote learning normalized it as another mode of "school". The evolution began with home-based learning being instituted on a routine basis, where students stay home one day a month or fortnight, mainly as a way to familiarize students and teachers with remote learning as a contingency against subsequent pandemic-induced disruptions as has already happened in Singapore during the pandemic (Tan and Chua 2021). We see schools increasingly becoming delocalized in subsequent decades, where students can connect to their classes remotely or attend in-person as circumstances or preference dictate. Since the home environment may not always be the most conducive for learning, co-learning spaces will become commonplace. Modeled after coworking spaces where companies lease office space or traveling workers rent a desk for a day or two, students settle into an individual "pod" or as a small group of peers in mini classrooms to attend their lessons on the other side of town, the country, or the world. Students from small remote communities or those from impoverished neighborhoods can receive a quality education at bigger schools without geographical constraints. Inter-school collaborative learning, up to and including those at an international level, is not uncommon and allows for cross-cultural learning that promotes pluralistic understanding and empathy. The co-learning spaces may blend formal and informal learning opportunities, synchronous and asynchronous learning modalities, as well as provide the socialization and interaction among peers that home-based learning does not. As mentioned above, the demands on teachers in 2050 won't be easy. Technologies would certainly have been developed to facilitate and enable more naturalistic remote presence and interactivity between teachers and learners. Of particular relevance to us would be the ways in which science practical work might be conducted in such settings. Perhaps such co-learning spaces would be co-located with community libraries and science centers/museums to jointly form satellite venues for both formal and informal learning. But most importantly for such *delocalized schooling* to have happened successfully, researchers and practitioners must have studied, developed, and refined the pedagogies and management techniques for hybrid classes where some students are physically present while some are remotely connected.

While all these prospects may be futuristic to us in the 2020s, we are confident that you, our colleagues in educational research, have continued to study teaching and learning as a learner-centered and hence human endeavor.

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Contents

Part I
Questions and Questioning in Science/STEM Education

Chapter 1
Commentary for Part I: Educating Students for Good Questioning in Science/STEM

Yann Shiou Ong

A common thread across the three chapters in Part I is the practice of *good questioning* in science/STEM. Chapter 2 by Uchinokura, Kusuhata and Hiroshi and Chap. 3 by Regunathan, Tan, and Koh discuss the practice of students asking/posing questions. Chapter 4 by Leung involves deliberating the trustworthiness of reports on science-related issues. I assert that the deliberation of trustworthiness requires good questioning as it involves asking critical questions (Walton & Godden 2005; Walton 1996) to elicit information from such reports that help determine their trustworthiness and subsequently, the reader's placement of trust. Examples of such critical questions include: who are the authors/funders of the research and do they have a biased agenda? Is the research study reliable and valid? Is the claim/conclusion sound, based on the research design that includes methods of investigation/data collection and data analysis? What evidence do the authors have and are they sufficient to support the claim/conclusion? Critical questions could be asked inter-personally of one another, such as during peer discussion, or intra-personally as questions on our mind as we review the reports.

1.1 Questioning as an Epistemic Practice

Questioning can be considered an epistemic practice, which is "a socially established set of activities directed towards common epistemic goals" (Watson 2018, p. 78). To elaborate, drawing upon Kelly and Licona's (2018) interpretation of epistemic practices, framing good questioning as an *epistemic practice*–rather than a process skill or method in science/STEM–implies that good questioning is interactional (observed

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among people of a community through their coordinated activities), contextual (situated within sociocultural norms and practices), intertextual (involves communication of discourses including signs and symbols in a historically coherent way e.g., past discourses have bearing on present questioning), and consequential (legitimized knowledge established through questioning exemplifies power and culture of the community). The epistemic goal of questioning is to seek out information to help us form trustworthy beliefs and decide how to act (Watson 2018). As a practice cannot be sufficiently defined by a finite set of rules and descriptions to effectively guide the reasoning and action necessary to enact the practice (Ford 2015), framing questioning as a practice rather than a process skill thus implies that, just like other practices, it is operationally challenging and perhaps near impossible to describe in reasonable details how to ask questions.

1.2 Good Questioning Versus Asking Questions

Readers familiar with the practice of "asking questions" might wonder if "good questioning" is just a synonym of the former. Afterall, "asking questions" as elaborated in the USA Next Generation Science Standards (NGSS) (NGSS Lead States 2013) and "posing questions" in the Singapore Ministry of Education's interpretation of scientific practices i.e., Ways of Thinking and Doing in Science (MOE 2021) seem to describe the same practice, for example. However, the difference between asking question and good questioning is non-trivial. Asking questions implies the competency to elicit any information. On the other hand, good questioning requires the competency to elicit *worthwhile* information through making appropriate judgements about what information to elicit, from whom, when, and how to do so (Watson 2018). Of course, not all questions are asked with eliciting information as the goal. For example, during argumentation, questions can be asked to elicit information from someone with the goal of challenging their claim or justification and thus casting doubt on their argument. Nevertheless, such questions still function as a speech act to elicit information from someone.

1.3 Why Should We Educate Students for Good Questioning in Science/STEM

Since "[q]uestioning initiates, guides and shapes inquiry" (Watson 2018, p. 8), it stands to reason that questioning likewise initiates, guides, and shapes disciplinary inquiry such as scientific inquiry as well as interdisciplinary inquiry such as STEM problem-solving. Good questioning perhaps also accounts for how serendipity plays a part in some scientific discoveries. As Louis Pasteur aptly put it, "in the fields of observation, chance only favours the mind that is prepared" (Vallery-Radot & Devonshire, 1917). When the opportunity presents itself, it is only the prepared mind of a good questioner with deep, disciplinary expert knowledge who can competently elicit worthwhile information from nature i.e. get nature to "speak" (Ford 2008. p. 408) that will end up pursuing an intellectually virtuous or meaningful line of inquiry. Even if such a line of inquiry does not lead to success, there will be much to be learnt from the failure. The above rings true even for more mundane, "business-as-usual" lines of inquiry. Thus, good questioning plays a significant role in the construction of knowledge claims/solutions to problems. Additionally, good questioning during argumentation in challenging someone's proposed argument, especially in light of epistemic criteria or ideals and reliable processes for arriving at the (inter)disciplinary knowledge claims, contributes towards the peer review process which is the current gatekeeping mechanism for knowledge claims. Thus, good questioning arguably supports both the goals of construction and critique of knowledge claims (Ford 2008), which in turn correspond to the intellectual virtues of inquisitiveness and healthy scepticism.

1.4 What the Chapters Tell Us About Questions and Questioning

Collectively, the three chapters in this section spanned the practice of questioning across the elementary, secondary, and post-secondary education levels. Chapters 2 and 3 focused on students' epistemic practice of asking questions at different grade levels and in different contexts. Both studies focused on the nature or type of questions asked by students, that is , what counts as good questions. Chapter 2 by Uchinokura, Kusuhata and Hiroshi determined fourth versus sixth grade elementary students' understanding of researchable questions in science, i.e., questions appropriate for answering through scientific inquiry, by asking students to identify researchable from non-researchable biology related questions and to generate their own questions based on a physics experiment. The researchers found that while it was fairly easy for the students to identify the researchable questions, only a limited number of students could pose researchable questions i.e., *what* and *how* questions; most students asked *why* and closed questions unsuitable for answering through science inquiry. In Chap. 3, Regunathan, Tan, and Koh compared and contrasted middle school students' questioning patterns during group presentation of their solution to a STEM problem after experiencing either the problem-centric approach or solution-centric approach integrated STEM instruction. The researchers did not find any statistically significant differences in the questions raised by students who experienced the different integrated STEM instruction. However, they noted that ontic questions (questions foregrounding the nature of entities, such as "What is a force?" or "What is the difference between mass and weight?") were asked most frequently, followed by causal questions, while epistemic questions seeking justifications and understanding of how we know what we know and why we should trust a claim, were posed the least. Finally, Chap. 4 by Leung described how a lesson unit designed using a practice approach to the nature of science (NOS) fostered Hong Kong SAR undergraduate students' scepticism towards placement of trust in science experts towards science-related social issues. These students were enrolled in a general education course and thus, not all of them have strong science background. Leung found an increased in the students' understanding and concern about trust placement as well as their understanding of NOS as indicated in students' reflective journals. However, some challenges remained in the students' trust placement.

1.5 Questioning in the Future of Science/STEM Education

In their **Notes to Our Future Colleagues**, the authors of the three chapters have depicted a future where integrated STEM teaching and learning is the default classroom practice, with students and teachers working toward creating solutions for real world problems (Regunathan and colleagues, Chap. 3). As such, students' questions-driven curricula becomes a reality, as students pose the questions they would like to explore and answer—many of which would be interdisciplinary in nature—through open inquiry approaches as students work collaboratively within learning communities comprising peers and students of different age groups, parents, teachers, and other experts to learn the necessary conceptual, procedural, epistemic, and social knowledges in order to answer their questions (Uchinokura and colleagues, Chap. 2). For students to be competent in directing their learning against the backdrop of the infodemic in the future, they need to achieve a good grasp of the epistemic practices in various disciplines in order to successfully distinguish trustworthy information from misinformation and disinformation. The placement of trust does not merely involve rationale thinking. Emotions also play an important role in the placement of epistemic trust on knowledge claims as emotions could mediate the cognitive, metacognitive, motivational and social aspects of trust placement (Leung, Chap. 4). This leads to the question of whether good questioning–including asking of critical questions to elicit worthwhile information–might also be mitigated by emotions and to what extent.

In our pursuit to develop students' ability to ask good and meaningful questions in science/STEM learning activities, educators need to be mindful not to only develop merely the skill of asking questions, but rather, the epistemic practice of asking good questions in science/STEM. Practice denotes a way of being, a disposition, or habit of mind. We ask questions because it is the appropriate act in a given context, such as when we have a need to know more, or when we have doubts about the soundness or trustworthiness of a claim/argument. There also needs to be an understanding of what "good" questions in science/STEM look like. For example, as articulated in the US NGSS, good scientific questions in the K-12 setting are questions that are researchable or can yield answers through science inquiry in the classroom. Such questions were the target of research by Uchinokura and colleagues (Chap. 2). And what about good questions in STEM activities? While Regunathan and colleagues (Chap. 3) categorised the nature of students' questions related to STEM solutions as ontic, casual or epistemic, are all three types of questions equally good? Is it desirable to have students pose a mix of all these types of questions or should some types of questions be prioritised over others? And to achieve what goals?

In closing this commentary, I propose two question prompts for readers to consider, with the intention of generating some worthwhile research questions for future inquiry into good questioning. Firstly, should instruction aimed at developing students' practice of good questioning for construction/critique of knowledge claims be well-structured (e.g., using the Question Formulation Technique created by the Right Question Institute (rightquestion.org)) or open-ended (e.g., students ask questions freely)? Or perhaps a progression from structured to open-ended as scaffolding is provided then faded? Secondly, on questions for critique of knowledge claims, how should students be taught to frame critique questions/critical questions to minimize the loss of face when critiquing peers' ideas (or even the teacher's ideas!) in cultures where face and respect for authority are highly valued? I invite readers to take on the challenge of answering either of the two questions I have posed, or perhaps be inspired to generate further good questions for science/STEM education research communities to pursue after reading this commentary.

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Chapter 2
Primary School Students' Understanding of Posing Questions for Scientific Inquiry

Shingo Uchinokura, Misato Kusuhata, and Naoya Hiroshi

2.1 Introduction

A cognitive tool that is frequently used in education and is important for teaching and learning science for all grades in schools is asking questions. Both teachers and students have opportunities to ask questions in the classroom. Based on observational studies conducted in high school classrooms, teachers often ask students more questions during lessons, as compared to students (Dillon 1988). While teaching science, teachers ask questions to determine the students' understanding in formative assessments, evaluate higher-order thinking skills, stimulate inquiry into the natural world through investigations, encourage problem-based learning and practical work, and invoke their reflection on practices followed during lessons (Chin 2006, 2007; Chin and Osborne 2008; Oliveira 2010). From the perspective of social language, classroom discourse is controlled by teachers' speech acts, which include asking questions (Mehan 1979; Lemke 1990).

However, although the number of students asking questions depends on their age, and the fact that older students seldom ask questions (Dillon 1988; Osborne and Reigh 2020), students asking questions should not be so inadequate as to impede their learning of science. Students' questions contribute to constructing knowledge, pursuing investigations, fostering discussion and debates in classroom discourses, monitoring and self-evaluating their understanding, and increasing motivation and interest to understand a topic (Blonder et al. 2008; Chin and Brown 2002; Chin and

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Osborne 2008; Herranen and Aksela 2019; Kuhn et al. 2020; Osborne and Reigh 2020). The types of questions that students ask while learning science were identified through classroom observations during lessons and interviews, before and after instruction (Chin and Brown 2002). These were categorised into basic information questions and wonderment questions. The basic information questions included factual or procedural questions. Factual questions usually only require the recall of information and are often closed questions, questions to clarify a given procedure, or questions on how a task is to be carried out. Wonderment questions require an application or extension of taught ideas, and focus on predictions, explanations, and causes, or resolving discrepancies and gaps in knowledge. The type of written questions students asks, after reading chapters from their textbook or scientific articles, were also explored (Hofstein et al. 2005; Marbach-Ad and Sokolove 2000). The questions ranged from low-level questions, related to facts and explanations of the phenomena, to high-level questions that could be answered only after further investigation.

2.1.1 Students' Questions for Scientific Inquiry

Amongst different types of questions that students ask while learning science, as abovementioned, inquiry-based or researchable questions have been specifically emphasised in inquiry-based science education (Herranen and Aksela 2019; Rönnebeck et al. 2016). The sciences are perceived as a practice that seeks to answer three overarching questions: *ontological*, *causal*, and *epistemic* (Osborne and Reigh 2020). An ontological question is a simple ontic question about observable entities, like 'What exists?'. A causal question seeks casual and mechanical explanations for the natural world. These are questions like 'What causes A?'. An epistemic question seeks reasons to justify scientific knowledge and argumentation, as well as believe them, like 'How do we know?' and 'Why should we believe this?'. These questions reflect scientific inquiry as an epistemic practice. The significance of asking questions in science learning is elaborated as follows (Herranen and Aksela 2019): Posing questions is an inquiry skill, and the questions are part of the inquiry. Inquiry-based science, which is considered a more authentic learning experience compared to superficial learning such as memorizing factual knowledge, is usually initiated by posing questions. Asking questions enhances students' motivation, interest, responsibility, or ownership of learning, as these are driving forces for inquiry. This is closely associated with the development of thinking, articulation, argumentation, and reasoning skills. In addition, the ability to ask questions, that is, problem finding or problem formulation in other contexts, could also be seen as a predictor of creative accomplishments (Runco 1994; Abdulla et al. 2018). In response to these discussions or competency-based science education reforms, developing the ability to ask questions and engaging students in scientific inquiry are emphasised in the science curricula in various countries, including USA and Japan. (Achieve 2013; National Research Council 2012, 2013; Ministry of Education, Culture, Sports, Science and Technology 2017a, b). These science curricula expect students not only to ask the lower-level type of information-seeking questions, but also to identify and ask researchable questions for practice during science learning. Indeed, asking questions is perceived as an important scientific practice.

Formulated questions for scientific inquiry are defined as specific types of questions that can be answered through scientific practices, including observation and experimentation (Cuccio-Schirripa and Steiner 2000; Hartford and Good 1982; Keys 1998; Allison and Shrigley 1986). Alfke (1974) proposed the idea of operational questions that support teachers and students in investigating scientific phenomena. The use of operational questions includes the manipulation of variables by eliminating, substituting, and/or increasing or decreasing the presence of a variable. By measuring the selected variables, through close observation and interpretation of the evidence, students can answer these questions (Allison and Shrigley 1986). Questions asked about the natural world can be classified as researchable or non-researchable. Some non-researchable questions include questions that students cannot collect data about because of a lack of content and procedural knowledge. In addition to enhancing the proficiency level of the science curriculum, resource issues in the science learning environment, such as better experimental equipment and facilities, are needed. However, there are certain non-researchable or improper questions for scientific inquiry that cannot be addressed even by experts. For example, questions related to personal preferences and ethical or political judgments are not suitable for natural science.

Studies have focused on the ability of high school students to ask better researchable questions and to refine their questions for further research (Blonder et al. 2005; Dori and Herscovitz 1999; Hofstein et al. 2004; Lombard and Schneider 2013). The participants in these studies were students participating in scientific research projects or advanced courses in which they could learn to pose questions in more authentic ways. The results indicate that open-inquiry activities have a positive effect on the way questions are asked. The questions asked by students through inquiry-based learning improved both quantitatively and qualitatively (Hofstein et al. 2004). In terms of the correlations between students' achievements and the level of their inquiry questions, while average and below-average performance students attempted to understand the subject matter to ask inquiry questions and hypothesise accordingly, high-achieving students attempted to ask questions on new things to apply the knowledge to other situations (Blonder et al. 2008). Research has been conducted on the quantity and quality of questions in practical work, such as during guided inquiry and problem-solving (Keys 1998; Otawa and Kinoshita 2014; Sakamoto et al. 2016). Keys (1998) reported that many students from a middle school in the United States formulated researchable questions that explored the effect of a variable on a scientific event through the generative model for teaching primary sciences, including those associated with the exploration, investigation, and reflection phases. Studies have also examined the impact of direct instruction on posing questions in primary school (Chin and Kayalvizhi 2002; Allison and Shrigley 1986), middle school (Cuccio-Schirripa and Steiner 2000), and high school (Hartford and Good 1982). Allison and Shrigley (1986) reported that students who learned through the teacher modelling of asking operational questions asked more operational questions than students who did not have this experience. While students in the group collaboratively asked researchable questions after some examples of questions had been shared with them, they faced difficulties asking proper questions individually without instructional modelling (Chin and Kayalvizhi 2002). It has been reported that the ability to ask questions is malleable; if students are explicitly taught how to ask and answer questions, they will progress better (Osborne and Reigh 2020).

There are different types of questions for inquiry; accordingly, taxonomies of researchable questions were proposed (Chin and Kayalvizhi, 2002; Krajcik et al. 1999). The questions asked by students from different schools range from researchable questions to non-researchable ones. Chin and Kayalvizhi (2002) reported that when a teacher asked sixth-grade students from a primary school to write down questions, they preferred to investigate in different scientific subfields individually; very few of their questions were identified as researchable. Instructional scaffoldings included showing examples of questions and talking with other students, which resulted in them being able to omit the non-researchable questions, and then collecting more researchable questions than in their first attempt. By categorising the students' questions, Chin and Kayalvizhi (2002) proposed a taxonomy of researchable questions: *comparison, cause-and-effect, prediction, design-and-make, exploratory, descriptive, pattern-seeking* etc. Their categories of students' questions showed the posed questions that guide the scientific inquiry and the expected types of answers to each question. On the other hand, Krajcik et al. (1999) proposed a simpler and more comprehensive categorization of posing questions for scientific inquiry: *descriptive*, *relational*, and *cause-and-effect questions.* In their definition, *descriptive questions* allow students to find out observable characteristics of phenomena, *relational questions* allow students to find out about associations between the characteristics of different phenomena, and *cause-and-effect questions* allow students to make inferences about how one variable affects another variable (Krajcik et al. 1999). As examples, "What materials dissolve in water?" is a *descriptive question*, "Which dissolves faster in water, salt of sugar? is a *relational question*, and "How does the temperature of water affect materials dissolves in water?" is a *cause-and-effect question.* Ontological questions in the more recent types of questions proposed by Osborne and Reigh (2020) have correspondence to descriptive and relational questions, and casual questions is the same as cause-and-effect questions by Krajcik et al. (1999). Epistemic questions are the meta-science questions of validation for these researchable questions. In this chapter, the framework of researchable questions proposed by Krajcik et al. (1999) is followed because the taxonomy of researchable questions by Chin and Kayalvizhi (2002) corresponded to the framework by Krajcik et al. (1999) and the framework could be expected to explain the types of researchable questions economically.

Hiroshi and Uchinokura (2019) reported that the skills of Japanese junior high school students associated with posing and identifying researchable questions could be differentiated according to the types of questions asked. In their study, the students were asked to answer whether each statement that mentioned the natural and mechanical world could be confirmed through investigation. If the statement was scientifically confirmable, it had to be changed from a declarative sentence to a question sentence. Identifying and asking *relational questions* was cognitively more difficult for them than *descriptive questions*. For the former type, they asked *closed questions* with binary answers without sufficient awareness of the criteria for comparison and reference. Most of the students asked questions using interrogatives that are specific words that have a grammatical function of focusing on subjects, objects, place, selection, amount, reasons and so on, such as 'why' and 'what'. These asked questions were interpreted as questions about the ontological meanings and backgrounds of natural things and events. However, students could differentiate researchable questions from non-researchable ones. This implies that they have epistemic knowledge of the two. There is limited research on this topic among primary school students. Additionally, it has not been determined whether there are any differences in the quantity and quality of questions asked by students of different grades. Gender differences in identifying scientific issues among older students have been reported (Organisation for Economic Cooperation and Development 2015). This study poses the following three research questions: How well do primary school students identify researchable questions? What kinds of questions (i.e. researchable or non-researchable) do students ask based on a given situation? Are there any differences in the understanding of posing questions for inquiry between fourth and sixth-graders and between male students and female students?

2.2 Methods

2.2.1 Participants

The participants of the study reported in this chapter comprised 99 fourth-grade students (8–9 years old), including 53 males and 46 females from three classes, and 98 sixth-grade students (11–12 years old), including 55 males and 43 females from three classes. The participants were from the same public elementary school in Japan and were taught by the same teacher. All fourth-grade and sixth-grade students who attended the school participated in the study, except the absentees. The national science curriculum in Japan, that is, the *Course of Study (CoS)*, was developed by the Ministry of Education, Culture, Sports, Science, and Technology (MEXT) and is revised approximately every ten years. Students in both grades were taught according to the 2008 revised *CoS* (MEXT 2008), which focuses on nurturing the ability to think, decide, and express. This was emphasised at all school levels from kindergarten to upper secondary school (Matsubara 2018), and according to the *CoS*, the sciences include physics, chemistry, biology, and earth and space science. The curriculum for fourth-grade students includes various topics such as simple electric circuits, changes in the state of matter, the human body, seasons, and the moon and stars.

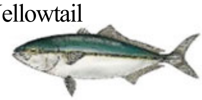
For sixth-grade students, topics include mechanics, electricity, combustion, solution, photosynthesis, and weather. However, the nature of scientific inquiry as a topic of epistemic knowledge is not taught explicitly in the national science curriculum, including the role of posing questions in scientific inquiry and the differentiation of researchable and non-researchable questions.

2.2.2 Data Collection and Analysis

To determine the understanding of primary school students regarding posing questions for inquiry in a topic-related manner, a paper–pencil test was developed. This included two types of assignments, which had to be completed without the teacher's help, other than clarifying any questions that students had about the assignments. In the first assignment, there were two items whereby the students were asked to identify which is the better question for further inquiry from among the two given questions and to provide reasons for their choice. In the second assignment, there was one item whereby the students were asked to pose as many questions for scientific inquiry in the given context as they could. In the first assignment, to determine their level of understanding, two items in which students had to differentiate researchable from non-researchable questions in the subject of biology were prepared. The first item to identify researchable questions asked about butterflies visiting the cabbage field (Item 1. *Butterflies in cabbage field*). This was selected to determine their understanding of *descriptive questions* and those using interrogative words like 'why'. The non-researchable question was, 'Why did butterflies come to the cabbage field today?' This could be interpreted as inquiring about the ontological meaning and background of natural things and events. The second item inquired was about the colour differences in fish in the shallow and deep-sea areas (Item 2. *Fish in shallow and deep-sea areas*; Fig. 2.1). This was selected to judge their understanding of *relational questions* and how students apply the epistemic knowledge of posing questions for inquiry to an unfamiliar situation in the primary school science curriculum. In the item, the non-researchable question was, 'Why do fish that live in the deep sea look worse than fish that live in the shallow sea?' This could be interpreted as inquiring about the appearance of fish based on personal preferences. The students were asked to choose a better question for further inquiry and list their reasons.

In the second assignment, to examine students' ability to ask researchable questions based on preliminary observations, a topic based on physics was identified. Students were asked to observe the temperature change of a solution by heating it in a microwave as depicted in Fig. 2.2. Note that the heating experiment was uncontrolled. Through an intentionally created unstructured situation, students had the opportunity to investigate different variables related to changes in temperature. They were encouraged to ask as many questions as possible. This assisted in determining the number and types of questions that students ask by focusing on the usage of interrogative words. The expected researchable questions in this context were *relational questions* that students find out associations between the temperature of the solution

Fishes in shallow sea

Types of Fishes	Blue mackerel 	Yellowtail 	Bluefin tuna 
Color of back body	Blue	Blue	Black

Fishes in deep sea

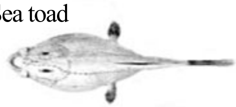
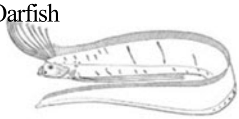
Types of Fishes	Splendid affonsion 	Sea toad 	Oarfish 
Color of back body	Red	Red	Gray

Fig. 2.1 Fish in shallow and deep sea around Japan

and the solute, amount, position, or container of the solution, and *cause-and-effect questions* that students make inferences about how one variable of the solution affects to the temperature of the solution.

All the participants completed the paper–pencil test. Structured interviews, whose duration ranged from 10 to 15 min, were conducted with 12 students from each grade after the test. The interviewed students were five males and seven females from the

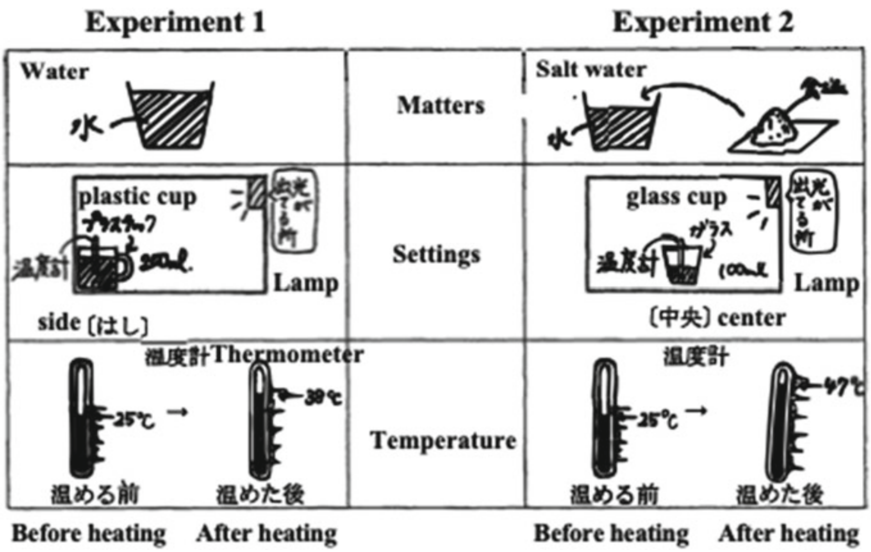


Fig. 2.2 Heating a solution in the microwave