Developing Teachers' Contingent Responsiveness in Dialogic Science Teaching via Mixed-reality Simulations:

A Design-based Study

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Declaration of originality

This thesis is the result of my own work and includes nothing which is the outcome of work done in collaboration except as declared in the Preface and specified in the text. It is not substantially the same as any that I have submitted, or, is being concurrently submitted for a degree or diploma or other qualification at the University of Cambridge or any other University or similar institution except as declared in the Preface and specified in the text. I further state that no substantial part of my thesis has already been submitted, or, is being concurrently submitted for any such degree, diploma or other qualification at the University of Cambridge or any other University or similar institution except as declared in the Preface and specified in the text. It does not exceed the prescribed word limit for the Education Degree Committee.

Abstract

Yu Lydia Cao
Thesis: Developing Teachers' Contingent Responsiveness in Dialogic Science Teaching via Mixed-Reality Simulations: A Design-based Study

The role of talk in science education has long been established; an essential part of learning science is for students to engage in scientific discourse. Nonetheless, productive science discussion is still rare in the classroom. The rarity can be partly attributed to the complexity of dialogic science teaching: teachers have to respond to the dynamic flow of student talk in the moment, orchestrate different voices towards a collective understanding, support the emergence of new ideas, ensure disciplinary rigour of scientific practice, and attend to the complex social relationships in the class. The construct of *contingent responsiveness* (CR) describes teachers' adaptive expertise in responding to student ideas in the moment to promote collective sense-making and classroom equity.

This study used a design-based research method (DBR) to co-design a technology-enhanced professional development (PD) programme with teachers of students aged 5-12 years old in Pakistan, incorporating mixed-reality simulation technology (i.e. Mursion) over four iterations. The effectiveness of the PD programme in supporting CR was evident in the significant shift in teachers' response patterns before and after the PD, shown by epistemic network analysis both visually and statistically. Furthermore, this study shed light on how to support teachers in developing CR using systematic conjecture mapping, tracing the path from design features to mediating processes, and then to the outcome. The conjecture map was refined over four iterations, which improved the design and learning theory over time. It was found that 1) adopting dialogic framings, 2) developing fluency with talk moves, 3) deploying flexible attention, 4) engaging in knowledge-based reasoning, and 5) experiencing metaphoric resonance could lead to CR. These processes were enabled by a combination of design features, i.e., mixed-reality simulations, talk moves, guided collaborative inquiry, case studies, and collective reflection.

This study achieved the dual goals of DBR, producing usable knowledge in the form of an effective PD programme and building a preliminary learning theory of CR. Furthermore, unpacking the mechanisms of the PD allows the design to be adapted and tested in other educational and cultural contexts, thus enhancing its adaptability, sustainability, and potential for scalability.

将这本论文献给我的妈妈谢媛，
一位伟大的母亲，
孝顺的女儿，
成功的女性，
我人生的榜样

To my mother Yuan Xie
A great mother,
A loving daughter,
An inspring woman,
My role model

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Chapter 1 Introduction

The role of talk in science education has long been established – an essential part of learning science is for students to learn to engage in scientific discourse (Kelly, 2007; Lemke, 1990; Martin & Veel, 1998; Phillipson & Wegerif, 2016). There is increasing empirical evidence for the role of talk in student learning, including evidence from large-scale randomised control trials (e.g., Alexander 2018; Howe et al., 2019). Nonetheless, productive talk is still rare in the classroom. The rarity of productive talk can be partly attributed to the complexity of dialogic teaching. Teachers have to respond to the dynamic flow of student talk in the moment, orchestrate different voices towards a collective understanding, support the emergence of new ideas, as well as attend to the complex social relationships among members of the class (Michaels et al., 2008). Orchestrating productive talk is especially challenging in subjects such as science which requires students to master a set of core concepts. Science teachers have to constantly balance the disciplinary rigour and student ideas to ensure the discussion is channelled towards the understanding of core science ideas and practices (Thomspon et al., 2016).

Various models of dialogic teaching exist in the literature, such as Dawe, Mercer, and Wegerif's "Thinking Together" (2000), Alexander's dialogic teaching (2020), Well's dialogic inquiry (1999), Resnick and colleagues' accountable talk (2018), and Nystrand's (1997) dialogically organised instruction. Despite the breadth of research on dialogic teaching and the variety of frameworks developed, little is known about how teachers manage the demanding work of moment-to-moment interaction and decision-making in classroom and how to prepare teachers for such a challenge (Lefstein, 2008; Lefstein & Snell, 2013; Sedova et al., 2014).

In my own experience as a math and science teacher in Calgary and Montreal in Canada, what I found the most challenging in my practice is contingently responding to student ideas to promote sense-making. Ideals and principles were not enough to productively respond to my students' ideas in real-time. Nonetheless, the spirit of dialogic teaching ought to manifest in these unassuming moment-to-moment interactions. Thus, I started my doctoral studies with one big question: **how can we support teachers to manage the complex work of dialogic teaching to think and act in the moment to productively respond to student talk?**

In this study, I adapted Feuersten't concept of 'contingent responsivity' and used the term 'contingent responsiveness' (CR) to describe teachers' adaptive expertise in responding to student ideas in the moment to promote collective sense-making and classroom equity. Using a design-based research method (DBR) and emerging technology (i.e., mixed-reality simulations, using the Mursion environment), my goals are to both produce usable knowledge in the form of the design of a professional development (PD) programme that can benefit the teachers and at the same time to develop preliminary learning theory, i.e., to understand how we can support teachers to develop CR.

Chapter 2 contextualises the problem space where the study is situated, i.e., at the intersection of dialogic teaching in science, teacher professional development, and educational technology. Various theoretical perspectives and conceptualisations of dialogic science teaching are synthesised, and put in dialogue with each other, generating a productive tension in practice. This chapter also defines the notion of CR, illustrates its nature as technical, intellectual, improvisational, and relational, discusses the problems in assessing CR from a monologic view and proposes a chiasm approach that is dialogic in nature. Finally, various approaches to PD are reviewed, identifying the unique affordances of mixed-reality simulations (MRS) in supporting teachers to develop adaptive expertise At the end of the chapter, two research questions are posed revolving around the dual goals of DBR, i.e., to produce usable knowledge in the form of design that supports teachers to develop CR and understand how that design works.

In Chapter 3, I critique the monologic causal model in education research, identify the key characteristics of design-based research (DBR), and explain the rationale for choosing DBR as a method for this research project. After explaining the research context and ethical considerations, I present the research design and the three phases of DBR.

Chapter 4 describes the first phase of the DBR, to understand the local context and identify high-level conjectures, design features, and mediating processes that could support teachers in developing CR, which are iterated over four design cycles.

Chapter 5 describes the second phase of the DBR, providing details on the design, implementation, and teacher feedback. At the end of each iteration, I return to the literature, putting teachers' feedback and literature in dialogue to refine the design for the next iteration. Each design cycle is summarised as a conjecture map.

Chapter 6 is part of the third phase of the DBR, i.e., evaluating the effectiveness of the PD programme (Research Question 1). Epistemic network analysis (ENA) is used to reveal differences in teachers' response patterns before and after the PD, both visually and statistically.

Chapter 7 is the second part of the third phase of DBR, i.e., uncovering the mechanisms of the PD programme (Research question 2) using conjecture mapping, tracing the path from design features, to mediating process and to outcomes. The emergence of each mediating process is identified using content analysis and systematic coding. The causal relations between each mediating process to CR (theoretical conjectures) and the connections to design features (design conjectures) are established based on empirical observation. A final conjecture map is presented at the end of the chapter.

In Chapter 8, I discuss the implication and limitations of these findings in Chapters 6 and 7 and propose a preliminary learning theory for CR that emerged in the DBR. I also reflect on the role of technology in this study, guiding principles in using MRS for PD, the design context in Pakiaran, as well as the affordances of the DBR as a method for doctoral studies and directions for future research.

Finally, in Chapter 9, I summarise the study and highlight the key findings as well as theoretical, methodological, and practical contributions. A number of recommendations are proposed based on this study. I then explain the plan of dissemination and the next steps for this study. I conclude the thesis with a personal reflection on my doctoral study as dialogue.

Chapter 2 Literature Review

This chapter contextualises the problem space where this study is situated, i.e., at the intersection of dialogic teaching in science, teacher professional development, and educational technology.

In this chapter, I start by discussing the diverse conceptualisations of dialogic teaching from a variety of theoretical lenses and research traditions. I then zoom into dialogic teaching, in the subject area of science and unpack the five different approaches to dialogic science teaching. Next, I discuss the notion of *contingent responsiveness* (CR) in dialogic teaching and illustrate its nature, i.e., technical, improvisational, intellectual, contextual, and relational. I highlight the problems in assessing CR from a monologic view and instead propose a chiasm approach that is dialogic in nature. Finally, I review a variety of approaches to teacher professional development, among which I identify the unique affordances of mixed-reality simulations (MRS) in supporting teachers to develop adaptive expertise. I conclude the chapter with research questions that revolve around the dual goals of DBR.

2.1 What is Dialogic Teaching?

The construct of *dialogic teaching* builds upon a long tradition of theoretical and empirical research on the role of talk in learning, teaching, and society. This body of research includes the works of philosophers (e.g., Bakhtin, 1986; Freire, 2000; Matusov, 2009; Wegerif, 2008), cognitive and cultural psychologists (e.g., Bruner, 1996; Vygotsky, 1978), linguists (e.g., (Barnes, 1976; Cazden, 2001; Wells, 1999) as well as many classroom researchers (Alexander, 2017; Boyd & Markarian, 2011; Edwards & Westgate, 1994; Lefstein & Snell, 2013; Mercer, 2019; Resnick et al., 2015). Due to the breadth of research on this topic, researchers and scholars have not reached a full consensus on its terminology and conceptualisation (Howe & Mercer, 2017).

Given the large volume of research and diversity in theoretical traditions, Lefstein and Snell (2013) summarised six approaches to dialogue:

1) Dialogue as an *interactional form* that involves two or more interlocutors
2) Dialogue as an *interplay of voices* in contrast to a monologue (Bakhtin, 1986)
3) Dialogue as *critique* to ideas to move beyond false belief to obtain truth (Plato, 2014)
4) Dialogue as *mediation for thinking* (Vygotsky, 1978)
5) Dialogue as *relationships* of respect, concern, trust, and appreciation (Buber, 1937)

6) Dialogue as *empowerment* for social justice and equity (Freire, 1970)

These approaches do not exclude one another. Viewing dialogue solely from one approach could result in a superficial way of teaching. For instance, when dialogue is only viewed as an interactional form while overlooking the actual content of the dialogue, a classroom can appear to be very interactive, but is in fact not dialogic (Boyd & Markarian, 2011).

From an epistemological perspective, language is a way of knowing – a means to an end, in line with Plato's critique, or as Vygotsky's devise of thinking. From a sociocultural perspective, social interactions mediated by language provide crucial 'inter-mental' experiences, shaping individuals' 'intra-mental' development (Vygotsky, 1978). Taking an epistemological perspective, dialogue is a tool for thinking or ascertaining the truth.

Wegerif (2020) argued that "any purely epistemological approach in education does tend to assume that there is a knowing self on the one hand and an external reality that is known about on the other hand" (p. 28). From an ontological point of view, language and dialogue are not only a medium of thinking and knowledge construction between selves and reality, but selves and reality are also part of the dialogue. In other words, engagement in dialogue is a way of being and relating to others, which aligns with Bakhtin and Buber's approach. In this view, talk is important not only because it is a vehicle for thinking and learning, but also because it fosters an orientation towards others (Bakhtin, 1986) – to respect, to listen, and to work with people who share different views (Wegerif, 2011).

Freire's conceptualisation of dialogue has both the epistemological and ontological elements. On the one hand, dialogue as a vehicle for literacy acquisition is fundamental to civil engagement and emancipation. On the other hand, he is against the "banking model" of education, where students are passive recipients of fragmented knowledge separated from their own reality. To him, teaching involves teachers and students engaging in a genuine dialogue originating from a profound love for the human race, co-constructing knowledge, and unveiling reality. Dialogue is both an instrument of change and a way of being.

These different epistemological and ontological views toward dialogue are also reflected in various conceptualisations of dialogic science teaching, which I examine in Section 2.2.

2.2 Dialogic science teaching: five approaches

Many research and teaching practices sought to leverage talk in science teaching and learning (Aguiar et al., 2010; Clarke et al., 2016; Ford & Wargo, 2012; Mercer et al., 2009; Mortimer & Scott, 2003; Ruthven et al., 2017; R. Wegerif et al., 2013; Wells, 1999; Windschitl et al., 2018). An essential part of learning science is learning how to engage in scientific discourse (Kelly, 2007; Lemke, 1990; Martin & Veel, 1998; Phillipson & Wegerif, 2016). The different approaches in dialogic science teaching and learning are underpinned by different epistemological and ontological views. In this section, I summarise five conceptualisations of dialogue in science: 1) dialogue as a pedagogical instrument; 2) dialogue as scientific practice; 3) dialogue as an instructional stance; 4) dialogue as the end goal; 5) dialogue as a virtue. It is important to note that these five approaches are not mutually exclusive in teaching practice. In fact, effective, engaging, and empowering science teaching requires interweaving the different approaches together, foregrounding certain approaches in a certain sequence of instruction. I elaborate more on the intersection of these five approaches at the end of this section.

2.2.1 Dialogue as a general pedagogical instrument for science learning

Dialogic science teaching under this approach is not subject-specific, but a *general pedagogical instrument* to teaching and learning. Many research and teaching practices foreground dialogue as a pedagogical instrument, i.e., use dialogue as a vehicle to improve teaching and learning outcomes (Hardman, 2019; Mercer et al., 2004). Alexander (2020, p. 1) sees dialogue as a tool of education and seeks to harness talk to "engage students' interest, stimulate their thinking, advance their understanding, expand their ideas and build and evaluate arguments, empowering them for lifelong learning and for social and democratic engagement." This approach finds its root in Vygotsky's view towards language as a thinking device. To Vygotsky (1978), thinking originates from social interaction, and social interactions are mediated by language, providing crucial 'inter-mental' experiences, which in turn shape individuals' 'intra-mental' development. Learning involves a passage from the social plane to individual understanding.

Besides Alexander's dialogic teaching, examples of this approach also include exploratory talk (Mercer & Dawes, 2008), accountable talk (Resnick et al., 2018), and inquiry dialogue (Reznitskaya et al., 2012). Teaching and research under this approach often emphasise the form of talk and the discursive practice (e.g., Vrikki et al., 2019). Dialogic teaching can be enacted through a set of repertoires, principles and indicators (Alexander, 2020). For example, in exploratory talk, there is an emphasis on ground rules and words associated with exploratory talk, such as 'I think', 'because', 'so' (Knight & Mercer, 2015). Dialogue is often used to elicit students' current understanding, show a learning trajectory, connect past activities to both the present and future activities, model what productive discourse looks like, make explicit the ways of using talk for collective reasoning and developing shared understanding (Mercer et al., 2009). Since the dialogic science teaching approach under this category is not subject-specific, it does not necessarily consider the subject-specific norms, genres, objects of discourse and epistemic practice (Sfard, 2008). Instead, this is the focus of the second approach that views *dialogue as a scientific practice.*

2.2.2 Dialogue as scientific practice

The second approach of dialogic science teaching views *dialogue as scientific practice* and highlights the dialogic nature of the scientific practice. Scientific knowledge is not indisputable facts, but socially constructed through conventionalised discourse practice in light of empirical evidence, and thus dialogic in nature (G. J. Kelly et al., 2000; Lemke, 1990; Osborne & Chin, 2010). Therefore, a fundamental aspect of learning science is to learn the language of the scientific community and discourse in practice.

The 'dialogue as scientific practice' approach seeks to establish coherence between science teaching and learning and authentic scientific practice. Dialogue is found in a range of activities that scientists conduct. Tan & Tang (2019) highlighted the role of dialogue in four major epistemic practices in science: questioning, inquiry, argumentation, and legitimising conceptual knowledge. Unlike the 'dialogue as a pedagogical instrument' approach, this approach foregrounds discourse as authentic scientific practice, such as scientific inquiry (Gillies et al., 2014; Hogan et al., 1999; Mueller, 1997; Russ et al., 2008), and scientific argumentation (Y.-C. Chen et al., 2019; Driver et al., 2000; Duschl & Osborne, 2002; Msimanga & Lelliott, 2012; Osborne et al., 2013; Ryu & Sandoval, 2012; Sampson & Clark, 2007).

In summary, the goal of science learning in this approach is to introduce students to the tools, practices, and language of science and explore how they could be applied to diverse social, technological and environmental contexts (Mortimer & Scott, 2003).

2.2.3 Dialogue as an instructional stance

This approach to dialogic science teaching emphasises *dialogue as a stance* towards instruction and considers discursive practice in service of dialogic stance (Boyd & Markarian, 2011; Ford & Wargo, 2012; Wells, 1999). This approach explicates the nuances of dialogic and monologic practice by making a distinction between ideology and discursive practice (Mortimer & Scott, 2003; O'Connor & Michaels, 2007). For example, classroom interaction can be ideologically monologic, but discursively dialogic (e.g., a popcorn discussion when teachers elicit student ideas but do not make use of the ideas). On the other hand, classroom interaction can be ideologically dialogic, but discursively monologic (e.g., when teachers present a variety of perspectives on a given issue, such as the Paley, Lamarck, and Darwin's account of evolution).

Mortimer and Scott (2003, p. 39) defined four classes of a *communicative approach* along with two dimensions of ideology (dialogic and authoritative), and discursive practice (interactive and non-interactive). The four classes of communicative approach are shown in Table 2.1. 'Dialogue as an instructional stance' approach to science teaching does not focus on one type of communicative approach, but on how they work together to support meaningful science learning and open up space for exploration (Boyd & Markarian, 2011; Scott & Ametller, 2007). This approach embraces the inherent tension between authoritative and dialogic discourse, which is a salient feature of science teaching and learning. On the one hand, students need to know accepted scientific knowledge (authoritative), and at the same time understand the tentative nature of the knowledge, how such knowledge is constructed, and the current debates in the field and gaps in such knowledge (dialogic).

Table 2.1 Four classes of communicative approach

	Dialogic	Authoritative
Interactive	Teachers and students explore ideas, generate new meanings, pose genuine questions, listen to each other, and work on different points of view.	Teachers lead students through a sequence of questions and answers with the aim of reaching one specific point of view.
Non-interactive	Teachers present a variety of perspectives on the same issue.	Teachers present one specific point of view that is usually deemed to be correct.

2.2.4 Dialogue as an end goal for learning

This approach considers *dialogue as a goal for learning*, which is rooted in Wegerif's (2013) ontological view of language. Wegerif (2008) argued that Bakhtin and Vygotsky's accounts of language are fundamentally incompatible. Vygotsky adheres to an epistemological perspective that language is a means towards an end. Vygotsky's account of learning depicts moving from a less sophisticated understanding to a more sophisticated version in the zone of proximal development (ZPD), i.e., moving from x-1 to x, to x+1. To Wegerif (2008), Vygotsky's theory of education is dialectic, not dialogic. A dialectic perspective assumes that meaning is grounded on identity, whereas a dialogic perspective sees meaning as not fixed, and that it is always situated within a dialogue among several voices.

To Bakhtin, meaning emerges from the gap between different voices, and Wegerif named this gap *dialogic space*. Therefore, from a dialogic perspective, knowledge is not understood as fixed and rectified. The progress of understanding is not moving from 'x-1', to 'x', to 'x+1'; rather it emerges from the inter-animation of different voices. Therefore, meaning emerges out of the tension between 'x-1', 'x', and 'x+1'. Dialogic theory suggests science learning is not only about replacing wrong ideas with right ones, but that it is more often about augmenting existing perspectives with new perspectives. In Bakhtin's words, "truth is not born nor is it to be found inside the head of an individual person, it is born between people collectively searching for truth, in the process of their dialogic interaction" (Bakhtin, 1984, p.110). To Bakhtin, truth is polyphonic—it cannot be reduced to or be found in a single voice, rather it is a *direction* that we move towards by dialogue of multiple voice (Bakhtin, 1981).

Shifting away from an epistemological perspective of viewing language as a tool, to an ontological perspective, has significant implications for science teaching, especially in viewing the relationship between canonical scientific concepts and student ideas (e.g., alternative conceptions, misunderstanding, nascent science ideas). A Vygotskian account would treat student ideas as something to overcome in order to move toward a more sophisticated explanation. A Bakhtinian account implies that learning is a shift of perspectives. Learning science means that you have established a dialogic relation with the different perspectives, that you know where a perspective is situated among different voices, and what makes it true or not true in what context. The dialogic view toward science is illustrated with the example of Newton and Einstein below.

Newton conceptualised gravity as a force, and his laws of motion dominated physics for 200 years. However, a slight inconsistency was found that Newton's laws of motion do not explain how mercury's elliptical orbit changes over time. Einstein had a different conceptualisation of force as the curvature of space, and his theories of special and general relativity explain all these discrepancies in Newton's law and offer the correct solution to Mercury's orbit. However, it was later found that Einstein's equations no longer hold when it comes to singularities such as black holes. The question is does Einstein's general relativity renders Newtonian physics obsolete? Does quantum physics make Einstein wrong? The answer is no, Newton's laws are still very useful—we still use them to plan complex space missions, and our GPS relies on Einstein's equations (Breadth, 2018). Some ideas that we know are no longer true, such as geocentrism, are still useful for predicting the location of planets. Science progresses through such paradigm shifts; the new paradigm does not render the old one obsolete, rather, it has better explanatory power to include them. Knowing that the earth goes around the sun does not mean that we do not see the sun rise in the morning. Dialogic theory suggests science learning is not mostly about replacing wrong ideas with right ones (although that can occur), but it is more often about the augmentation of existing perspectives with new perspectives. Dialogic theory suggests an ontological shift in the nature of scientific knowledge. That scientific knowledge is not just facts but also a network of perspectives in which new theories need to be understood by holding them together in tension with other theories.

Just as we saw in the Einstein and Newton example earlier, learning about general relativity is not to disregard Newtonian physics, but implies that learners can shift perspectives between them depending on the context. Dialogic theory suggests science learning is often about augmenting existing perspectives with new perspectives. In the 'dialogue as an end goal' approach, the primary goal of science teaching is to induct learners to join the dialogue as active participants and together improve the quality of dialogue as a virtuous community, which leads to the last approach, dialogue as a virtue.

2.2.5 Dialogue as a virtue

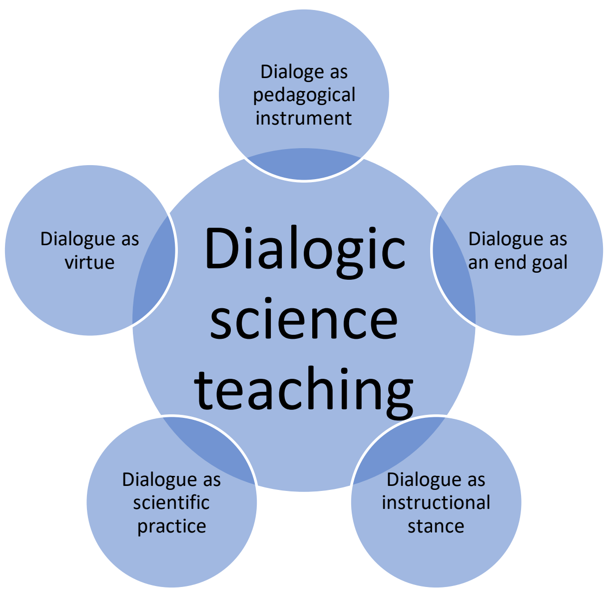
The *dialogue as a virtue approach* emphasises virtues, such as honesty, open-mindedness, disposition towards the truth, that are integral part of science as progressive dialogue (Bereiter, 1994). Science in its nature is a contested dialogue among scientists as they must persuade each other of the validity of their results and interpretations. Scientific knowledge originates from an accumulated body of experience and is shaped by the scientific discourse and rhetorical intentions (Anderson 2003). Despite the appearance of certainty, scientific knowledge is produced in paradoxical progress that focuses on uncertainty and shared intellectual authority (Ford and Forman, 2015). What distinguishes dialogue of science from other types of discourse then? What makes science as a progressive discourse?

McIntyre (2019) argues that what distinguishes science from non-science is what he calls "the scientific attitude"—the willingness to change your ideas in light of evidence. The authority of science is found in its rigorous procedure and practices (e.g., peer review, transparency, replication of experiments) and upholding of virtues such as honesty, integrity, and truth. Therefore, dialogic science teaching is not just about sharing epistemic authority with students or promoting scientific argumentation, but also about cultivating virtues and embracing the scientific attitude (Fortes & De Brasi, 2022). In dialogic science teaching, therefore, it is important to support students to develop discernment of trustworthy communities from 'echoing chambers' and have trust in science as an open dialogic community governed by dialogic ethics of seeking the truth over self-interest.

2.2.6 Dialogic science teaching in practice

As mentioned at the beginning of the section, these five approaches to dialogic science teaching are not mutually exclusive but overlap in practice. I take a dialogic stance toward the five approaches by putting all these approaches into dialogue (See Figure 2.1).

Figure 2.1 Putting five dialogic science approaches into dialogue



In practice, sometimes we want to foreground one approach over others, combine two approaches, or shift between them. For example, when teaching evolution, I could use a dialogic framing to plan for the unit, oscillating between introducing different historical accounts of evolution (presenting Paley, Lamarck, and Darwin's account of evolution) and having students engage in investigation and scientific argumentation about the merits and flaws of each theory (argumentation as scientific practice). I could leverage dialogue as a pedagogical instrument in small group discussions and explicitly teach students productive ways of engaging with each other's ideas, such as exploratory talk. When leading a whole-class discussion, I might focus on dialogue as an end goal, holding various perspectives in tension, widening, and deepening the dialogic space to improve student discourse on the topic. Finally, it is important to cultivate the scientific attitude and dialogic virtues in students to seek truth over self-interest, to change their ideas in light of evidence.

2.2.7 Summary

In this section, I reviewed dialogic science teaching at a conceptual level. I categorised dialogic science teaching into five conceptual categories each with distinct features:

1) dialogue as a pedagogical instrument,
2) dialogue as scientific practice,
3) dialogue as an instructional stance,
4) dialogue as an end goal
5) dialogue as a virtue

In practice, these five conceptualisations are not mutually exclusive but should be used with flexibility. In the next section, I zoom into dialogic science teaching at the level of classroom practice, specifically focusing on how teachers lead a dialogic science discussion.

2.3 Science discussion

2.3.1 What is a dialogic science discussion?

A class discussion is a loosely defined term that can be interpreted as an activity (e.g., pair discussion, small group discussion, whole-class discussion), or a type of talk that focuses on exchanging ideas (Alexander, 2020). So, what makes a science discussion dialogic?

Mortimer and Scott's (2003) communicative approach is helpful in making distinctions between various types of science discussion as shown in Table 2.2: sense-making discussion, exposition, funnelling, and recitation. This study focuses on dialogic-interactive discussion, which I also refer to as "sense-making discussion". Sense-making discussion requires active participation and the presence of different perspectives with the goal of "making sense" of something together (e.g., a puzzling phenomenon). Sense-making discussion is different from exposition, which often involves one speaker that reviews a range of perspectives. Sense-making also differs from funnelling, which is interactive with the intention to "funnel" students towards the intended answer(s). Lastly, sense-making discussion is different from recitation, which is both non-interactive and authoritative.

Table 2.2 Four types of science discussions

	Dialogic	**Authoritative**
Interactive	Sense-making discussion	Funnelling
Non-interactive	Exposition	Recitation

I am in agreement with Mortimer and Scott (2003) that these four types of discussion should be used with flexibility. The reason that I focus on sense-making discussion is that it is arguably the most challenging discussion to facilitate from a teacher's perspective—as it requires much improvisation from the teacher to orchestrate different perspectives to help students to advance the dialogue.

Sense-making discussion can happen in a small group or in a whole-class setting. So far, much research has focused on small group discussions and has strong evidence for their positive effect on learning (e.g., Howe & Abedin, 2013). Recently, a large-scale study has shown productive forms of teacher-student dialogue that are positively associated with curriculum mastery (Hennessy, Calcagni, et al., 2021; Howe et al., 2019). However, little is known about how to help teachers to develop the skills to lead whole-class discussions, which is the focus of this thesis.

2.3.2 Conceptualising discussion as a dialogic space

Collective sense-making is a shared space where different lived experiences, perspectives, and ways of knowing and understanding are not only acknowledged and respected, but also resonate, merge, clash, to create new ideas. Wegerif (2007) called such a shared space of mutual resonance as *dialogic space*.

Wegerif (2010, p. 66) described dialogic space as:

> The space of meaning that we enter into when we engage in dialogue together…Dialogue, whereby the outside enters the inside and the inside enters the outside, is a way of unpicking some of the boundaries that locate us within identities. The space that dialogues open up is the space of the boundary, that is to say, the space of infinite possibility that was there before the boundary was drawn.

Based on this definition and Wegerif's elaboration on dialogic space in his work (Wegerif, 2007b, 2010, 2011b, 2017; Wegerif & Major, 2019), I summarise the four features of dialogic space.

1) Presence of more than one voice

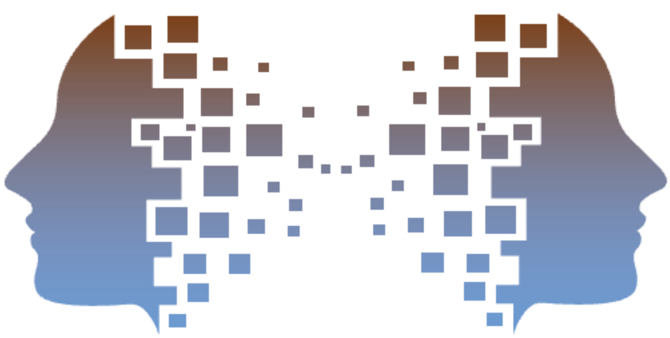
The defining feature of dialogic space is the presence of at least two voices or perspectives (Wegerif, 2011b). To Wegerif, dialogic space presupposes a dialogic gap between irreducibly different perspectives. It is important to note that multiple voices do not necessarily require the presence of multiple people being in the same physical space at the same time. Dialogic space expands across time and space, encompassing voices in both living and non-living things. For example, Bakhtin (1986) explained that he could engage in dialogue with voices from ancient Greece. Buber (1937) accounted for dialogue with trees and animals. Depending on how we position and orient ourselves, reading a book can either be monologic that is, receiving a message from an authoritative voice, or as a dialogue with the author. From a dialogic perspective, reading a text is not to ascertain the unknown intentions of the author, but meanings are stimulated by the text from a new perspective in a new context.

2) Bilateral flow, mutual resonance, blurring of individual boundaries

Wegerif (2010, p. 66) described dialogue as "the outside enters the inside, and the inside enters the outside, … a way of unpicking some of the boundaries that locate us within identities." In a dialogic space, ideas flow both ways—there is no sender and receiver. Nonetheless, just the free flow of ideas does not make a dialogic space. Two people can seem to be engaged in a dialogue, but if there is no mutual resonance of the ideas, there is no understanding or learning. Therefore, in addition to the bilateral flow of ideas, there must be mutual resonance among ideas, which Wegerif (2017, para. 2) describesd as "ideas resonate together, merge in some ways, clash in others and stimulate the emergence of new ideas."

This mutual resonance can also be thought of as entanglement and intertwining of ideas. Drawing from Rommetveit (1992), Wegerif (2017, para. 5) illustrated that dialogue is a loop that which "the 'other' is always already on the inside of every utterance…because each utterance responds to what the other has said in a way that is intended to relate back to the other." This metaphor of dialogue as a loop echoed with Bakhtin (1986, p. 89) who maintained that "our speech…is filled with others' words, varying degrees of otherness or varying degree of 'our-own-ness'." To Bakhtin, words and ideas do not belong to individuals because as we speak and think, we are constantly responding to another utterance. Figure 2.2 illustrates that in dialogic space, the boundaries of individuals are blurred. There is no clear boundary of who is thinking and whose idea because we are thinking together.

Figure 2.2 Blurring of individual boundaries in a dialogic space



3) Infinite possibilities

There are infinite possibilities in dialogic space; in other words, the outcome of a dialogue is not predetermined. As Wegerif and Major (2019, p. 114) described, "outcomes cannot be determined in advance because, in principle, any real dialogue opens up an infinite potential for creating new meaning." What do infinite possibilities look like in a classroom when there is a set of instructional goals? In my research, I observed a small group discussion in which children are observing the vibration of a guitar string to understand the source of the sound. The teacher asked students, "where does the sound come from in a guitar?" At first glance, this seems to be a closed-ended question with one correct answer that sound comes from the vibration of the string. However, as children observed the guitar string, they noticed the hole in the middle of the guitar and the thickness of different strings and how they made a different sound. These observations led them to question the role of a hole in producing the sound and the variability in the thickness of the material. This example shows that even though we can start a dialogue with some goals in mind, what occurs in the dialogic space cannot be pre-determined. The infinite possibilities reside within the opening of a dialogic space.

4) Irreducible to external surface features

Lastly, dialogic space is irreducible and cannot be completely defined by these external surface features, such as the words used, the physical space, or the ground rules. To Buber (1937), what makes it dialogic is an orientation towards others. Wegerif (2017, para. 14) explained that "to try to define dialogues in terms only of the external and the visible is to try to kill precisely what makes them not only useful but essential to education - the internal and invisible dialogic space that makes new connections, new insights and new understandings possible."

When looking from the outside, we see a group of children sitting in a circle and politely taking turns to speak, following ground rules. However, this doesn't necessarily indicate the opening of dialogic space. Sometimes dialogic space can take place when there is little exchange of words. In Fujita et al. (2021), the shared thinking among children was at least in part done by their fingers as they pointed the key to solving the puzzle on the tablet. From an outside perspective, the dialogic space was inferred from their body language as they converged around the tablet and their fingers. The space metaphor allows us to speak of the opening, widening, and deepening of the dialogic space, which is useful to understand the role of teachers and their responses during a class discussion, which I elaborate on in section 2.5.

2.3.3 What is involved in sense-making?

So far, I mainly draw on dialogic education literature, leading me to conceptualise sense-making discussion as a dialogic space. For the following section, I draw from the science education literature to understand what is involved in sense-making from a science education perspective.

The term *sense-making* or *sensemaking* has gained much attention since 2007, evident in the drastic growth of literature on this topic. Sense-making is something we can relate to, something innately human—we have all tried to make sense of things at various stages of our life. Research shows that babies and young children sense-make, that they think, draw conclusions, make predictions, look for explanations, and even do experiments (Gopnik et al., 2001). Very young students can sense-make beyond simply describing their observations and develop a beginning understanding of concepts once considered too abstract for them (Duschl et al., 2007).

Maybe because of its intuitive appeal, there is a lack of theoretical and conceptual agreement on what sense-making entails (Odden & Russ, 2019). To better understand sense-making, I present a number of definitions of sense-making proposed by scholars from different theoretical perspectives in science education, and then I summarise the distinctive features of sense-making that they all agree on.

Cognitive science

From a cognitive science perspective, Kapon (2017, p. 166) describe sense-making as "a complex [cognitive] process…in which a learner constructs and reconstructs a series of self-explanations that evolve, change, replace one another, or merge into a new self-explanation." This definition focused on sense-making from an individual's cognitive perspective and highlighted the following:

1) the iterative and dynamic process of sense-making;
2) the active role of learners within an intra-mental space;
3) generation of new understanding.

Sociocultural perspective

Moving beyond an individual's intra-mental space, Warren et al. (2001) argued from a sociocultural perspective that sense-making encompasses "a varied complex of resources, including practices of argumentation and embodied imagining, the generative power of everyday experience, and the role of informal language in meaning making" (p. 532). According to Warren et al.'s definition, sense-making can happen both at the level of an individual and collective level, and it encompasses a variety of intellectual resources. Adding to and modifying (underlined) the list of features of sense-making from Kapon (2017), I arrive at:

2) the active role of learners <u>both intra-mentally and inter-mentally</u>

4) encompass a diversity of intellectual resources (e.g.., intellectual traditions, social practices, experience, ways of using language)

In agreement with Warrant et al., Campbell et al. (2016, p. 69) defined sense-making as "working on and with ideas—both students' ideas (including experiences, language, and ways of knowing) and authoritative ideas in texts and other materials—in ways that help generate meaningful connections." Nonetheless, they did not clarify what it means to "generate meaningful connections", which is specified by the discipline of science practice.

Disciplinary practice of science

From a disciplinary scientific practice, Schwarz and colleagues (2021) described sense-making as "wrestling with ideas, language, experiences, and perspectives in community to figure out how and why the world works; sense-making means proactive engagement in understanding the world by generating, using, and extending scientific knowledge within communities" (p. 114).

In this definition, most of the features we have seen so far about sensemaking are present. Furthermore, they emphasised generating mechanistic explanations ("how and why something works") and highlighted the importance of scientific practice in this process ("generating, using, and extending scientific knowledge within communities").

Adding and modifying the list of features of sense-making so far:

5) a focus on mechanistic explanation ("how and why something works")

A synthesised perspective

Finally, Odden and Russ (2019) attempted to bridge the fragmented field in sense-making by reviewing the major strands of literature on sense-making from cognitive science, epistemological frame, and discourse practice. Upon concluding that these different theoretical perspectives complement each other, they proposed an overarching definition of sense-making, applicable to a broader science education literature but distinctive to the confounding constructs, such as thinking, learning, explaining, modelling, and argumentation.

According to Odden and Russ (2019, pp. 191–192), sense-making is

> a dynamic process of building or revising an explanation in order to “figure something out”—to ascertain the mechanism underlying a phenomenon in order to resolve a gap or inconsistency in one's understanding. One builds this explanation out of a mix of everyday knowledge and formal knowledge by iteratively proposing and connecting up different ideas on the subject. One also simultaneously checks that those connections and ideas are coherent, both with one another and with other ideas in one's knowledge system.

They further specified the process of sense-making as “identifying a gap in understanding; shopping for ideas; piecing ideas together into a coherent explanation” (Odden & Russ, p. 192). Though the process seems linear, they acknowledged that this “simple process is likely repeated over and over—the process is iterative and nonlinear.

The definition that Odden and Russ (2019) proposed are mostly in accordance with what I have summarised so far. What is different in their definition from the others is that they identified the pre-requisites of sense-making: a gap or inconsistency of understanding. They also emphasised the distinctiveness of sense-making from other confounding constructs, such as scientific explanation, maintaining that “sensemaking involves building new knowledge or forging new connections between existing knowledge, whereas explanations can be generated without the need for any new knowledge or connections” (p. 198). Finally, to Odden and Russ (2019, p. 192), resolving inconsistency is paramount, and the end goal of sense-making is that “…if their sensemaking is successful, [learners] end up with a coherent explanation that fills in the gap in knowledge or resolves the inconsistency—at this point, things “make sense.”

To summarise the features of sense-making reviewed so far:

1) Learner's active engagement both intra-mentally and inter-mentally

2) Iterative process

3) Focus on mechanistic explanation (i.e., how and why something works)

4) Draw from a diversity of intellectual resources (e.g., intellectual traditions, social practices, experience, ways of using language)

5) Require an inconsistency or a gap in understanding

6) Generate new understanding (i.e., new to the learners, not necessarily new to the world)

7) Resolve inconsistency

2.3.4 Dialogue between the literature of dialogic education and science education

The features of sense-making from science education literature resonate with the principles of dialogic science teaching on many levels. For example, active intra-mental and inter-mental engagement correspond to the collectivity in dialogic teaching, and the iterative process resonates to the 'work-in-progress' mentality of dialogic teaching. The focus on mechanistic explanation can be seen as a deepening of dialogic space while the diversity of intellectual resources corresponds to its widening. The requirement of inconsistency or gap in understanding can be seen as the opening of dialogic space. Generating new understanding speaks to the fostering of creativity in dialogic education.

The only divergent point between science education and dialogic education is the "resolving inconsistency", which is underpinned by an identity-based ontology. A dialogic perspective would not necessarily require resolving inconsistency, but rather an augmentation of perspective and flexibility in the shift of perspectives. A dialogue is forward-looking that aims to open up more questions and possibilities rather than closing them down. This is reflected in *maintaining* as a dialogic function, signalling the ongoing nature of dialogic space. Scardamalia and Bereiter (2014, p. 400) explained that "many people still think of scholarly knowledge as advancing toward (though perhaps never reaching) final truths: how the universe actually began, the true history of the invasion of Iraq, and so on. But advances in theoretical and historical knowledge raise new problems and open new possibilities." Such a mentality of continuous improvement and 'work-in-progress' is fundamental in dialogic education.

From a dialogic perspective, scientific concepts are understood as a network of practices in relation with each other rather than in isolation. As discussed earlier, knowing that the earth goes around the sun does not mean that we do not see the sun rise in the morning. Dialogic theory suggests science learning is not mostly about replacing wrong ideas with right ones (although that can occur), but it is more often about augmenting existing perspectives with new perspectives. Gadamer (1975) outlined the idea of a fusion of horizons in a dialogue between people, a shared meaning space. A's perspective and B's perspective are included and made sense of in a larger emergent third perspective. A difference here is they are not reduced to commensurability or the lowest common denominator, but that there is drive to a creative leap forward in order to understand both positions in a bigger more inclusive vision. From a dialogic perspective, progress in science, therefore, is not only about resolving inconsistency (though that is important), but also more about creatively finding a better perspective from which both can make sense. The importance of Einstein's theory is not simply to account for Mercury's changing orbit (which cannot be predicted accurately according to Newton's law), but a creative leap forward to a new theory in which both perspectives are made sense of, resulting in a fusion of horizons.

2.3.5 Adaptive expertise in facilitating sense-making discussions

As we see in the previous section, sense-making is complex. Facilitating sense-making as a whole class discussion is even more complex. Teachers have to:

- decide how to elicit and make good use of the diversity of student ideas;
- judge which ideas and questions will be most productive to pursue;
- attend to the intersection between students' everyday ideas and disciplinary ideas;
- coordinate the ideas and perspectives of learners to move thinking forward;
- channel discussion toward an understanding of disciplinary core ideas (Harris et al., 2012; Robertson et al., 2016; Wells & Arauz, 2006).

Studies have found that the teacher's response, conceptualised as the third turn in classroom discourse, plays a vital role in determining opportunities for student sense-making and the quality of classroom discourse (Michaels & O'Connor, 2015; Park et al., 2017). For example, Boyd and Rubin (2006) found that the contingency of teachers' questions mattered more than the nature of the question itself (e.g., open or close-ended) in terms of extending student talk. Similarly, Grinath and Southerland (2019) found that the most important aspect of teacher assistant talk for elevating explanatory rigour of student discourse was the response to student contribution rather than the type of question.

Teachers need to contingently respond to the dynamic flow of student talk in the moment and the changing situations in the classroom. What kind of expertise is required of teachers to contingently respond to student ideas in the moment?

In general, there are two types of expertise: routine and adaptive expertise (Hatano & Inagaki, 1986) Routine expertise is characterised by the mastery and fluency of procedures in a given context and is focused on efficiency. On the other hand, adaptive expertise is characterised by flexibility and creativity and is focused on innovation in addition to efficiency (Hatano & Oura, 2003; Schwartz et al., 2005). Therefore, the development of adaptive expertise requires a balance between efficiency and innovation: developing fluency with routines whilst having the flexibility to apply it across contexts and come up with new responses/solutions. Because CR hinges upon teachers' capacity in responding to student ideas productively across contextual variation, CR is a viewed as a type of adaptive expertise, which is part and parcel of dialogic teaching.

So far, CR is rarely examined in dialogic education literature. In the next section, I draw on the literature on cognitive science, teacher noticing, and responsive teaching to do a deep dive into the nature and conceptualisation of CR.

2.4 Contingent Responsiveness (CR)

2.4.1 Definition of CR

In this study, *contingent responsiveness* (CR) is defined as teachers' adaptive expertise to respond to the dynamic flow of student talk in the moment to promote collective sense-making and classroom equity. The construct of CR has its origin in Feuerstein's *contingent responsivity* in the theory of mediated learning experience (MLE) (Feuerstein et al., 1991; Lidz, 1991). Lidz (1991) described 'contingent responsivity' as "the ability to read the child's cues and signals related to learning, affective, and motivational needs, and then to respond in a timely and appropriate way" (p. 109). Contingency is often seen as one characteristic of scaffolding, described by Pea as "interactive responsiveness that is contingent on the needs of the learners" (2004, p. 429). Wegerif (2013) also maintained that dialogic teaching implies contingent responsiveness within relationships, emphasising the importance of the teacher's judgement in the moment to contingently respond to and build on learners' voices, which he saw as the essence of a dialogic relationship.

2.4.2 Granularity of Contingent Responsiveness

Contingent responsiveness emphasises thinking and responding in the moment, which is part and parcel of dialogic teaching where teachers and students engage in a productive dialogue together. The phenomenon described by the term contingent responsiveness is not new. Teachers' responsiveness has been studied in various lines of research, such as teacher noticing and responsive teaching. Teacher responsiveness is also described at various granularity.

Schwarz et al., (2021) categorised responsiveness into the macro-, meso-, and micro-level. Responsiveness at a macro-level refers to teachers adapting instructions, lessons, and the curriculum in a response to student ideas and experiences, which is often referred to as *responsive teaching*. Micro-level responsiveness refers to the moment-to-moment interactions and turns of talk during a classroom discussion. The unit of analysis in micro-level responsiveness is usually by utterance or a turn of talk. Schwarz et al. (2021) identified meso-level responsiveness, a collective of utterances that coheres around a sense-making idea, which they named 'sense-making moment'.

Both micro- and meso- levels of responsiveness would require teachers to think on their feet and come up with responses under time pressure, and both would require teachers' in-the-moment reactions. The term of contingent responsiveness is useful as it conceptually distinguishes itself from responsive teaching by emphasising the constraint of time. Therefore, I propose categorising responsiveness into two categories: responsive teaching and contingent responsiveness. Responsive teaching, adapting lessons and subsequent instruction in response to student ideas that can be planned in advance. On the other hand, contingent responsiveness is time-bound and is situated in the moment.

Contingent responsiveness requires a different kind of competency from teachers than responsive teaching. It involves teachers thinking on their feet—to respond to the unpredictable flow of student talk in the moment, orchestrate different voices towards a collective understanding, support the emergence of new ideas, and attend to the complex social relationships among members of the class (Colley & Windschitl, 2016; Harris et al., 2012; Michaels et al., 2008).

2.4.3 Nature of Contingent Responsiveness

First and foremost, CR is *relational*. Buber (1937) saw dialogue as fundamentally relational and drew distinctions between two types of orientation toward others (whether humans or non-humans).

We can either objectify others as a means to accomplish our goal (I-It orientation) or enter a reciprocal relationship with others (I-Thou orientation). Wegerif (2016) views the key indicator of the 'I-thou' orientation as whether "we are open to the possibility that we might learn something."

Wegerif (2013, p. 35) maintains that "In order to teach at all, this relationship needs first to be established and then all teaching needs to be responsive to and build on the voices of learners. Education into dialogue is therefore ethical and emotional before it is cognitive." Similarly, Burbules thinks that dialogue is relation, which is best brought about by as "concern, trust, respect, appreciation, affection, and hope" (1993, p. 41). In addition, relationships are what sustain the dialogue, especially when it becomes difficult and contentious (Burbules, 1993). In other words, relationships among learners and teachers, the orientation toward others, and interest in other people and other ideas are what sustain dialogic interactions (Phillipson, 2020).

So far, we also have seen the fleetingness of CR which requires teachers' improvisation to respond in real time. The *improvisational* nature of CR is illustrated in a one-minute 28-second clip filmed in a classroom of Professor Deborah Loewenberg Ball, a math education expert from the University of Michigan. She counted 20 micro-moments when she had to decide how to react (Barshay, 2018).

In addition to improvisation, CR also has a *technical* dimension though it cannot be reduced to techniques (Kazak et al., 2015; Wegerif, 2007a). To Wegerif (2013), techniques are scaffold to productive dialogue, but not dialogue itself. The essence of dialogic teaching is in the moment during interaction with learners. Research consistently found the limitation of techniques in dialogic teaching. For example, teachers are capable of using techniques to elicit students' ideas and increase students' participation, they often find it difficult in helping students to expand and move their thinking forward (Hennessy & Davies, 2020). Chazan and Ball (1999, p. 7) maintains that "teacher moves are selected and invented in response to the situation at hand, to the particulars of the child, group or class and to the needs of the [subject]".

Meaning-making requires teachers to actively listen and engage with students' sense-making, meeting where they are, and facilitate the discussion using their professional judgment. Teachers need to manage competing ideals of dialogic teaching, such as between caring and critique, between individual autonomy and equitable discussion, between student interest and mandated curriculum (Lefstein & Snell, 2013; Sedova, 2017). All of these require teachers' *intellectual* engagement.

Finally, CR is *contextual*. A response that works in one context with one learner might not work in another context with a different learner. Teachers' response is shaped by many factors, such as their instructional goal, their knowledge about the learners and class, their pedagogical knowledge etc. CR requires teachers to be able to adapt in response to the changing contexts in the classroom.

In summary, contingent responsiveness is not only *technical* (making use of a variety of techniques such as talk moves), but also *intellectual* (making a professional judgement and engaging in collective sense-making with students), *improvisational* (being able to respond to the dynamic flow of student talk in the moment), contextual (being able to adapt in response to the contexts, situations and learners) and fundamentally *relational* (orienting towards students and being open about their ideas). The intricate dance among these dimensions is well described by Renshaw (2004, p. 7) dialogic teaching is "an artful performance rather than a prescribed technique: as the teacher must "follow and lead, to be responsive and directive" and must "require both independence and receptiveness" from students.

2.4.4 Operationalisation of CR

As discussed in 2.3.5, teachers' responses to student contributions, the third turn in a typical teacher-student exchange, plays a critical role in determining whether students have the opportunity to engage in collective sense-making (Park et al., 2017). Building upon Wegerif's (2010) metaphor of a dialogic space, CR can be operationalised as teachers' third turn in response to student contributions, i.e., *widening*, *deepening*, *maintaining*, and *shaping* the dialogic space, which I refer to as *dialogic functions*. Because discussion is conceptualised as a dialogic space, it is assumed that the dialogic space is open. Furthermore, though *initiate* and *feedback* are often associated with a monologic discourse controlled by teachers, they were included as part of the operationalisation because monologic moves/discourse could carry dialogic functions (e.g., Boyd & Markarian, 2011) and science discussion is often an oscillation between monologic and dialogic discourse (Mortimer & Scott, 2003; Phillipson & Wegerif, 2016; Scott & Ametller, 2007; Tabak & Baumgartner, 2004). Each dialogic function is discussed in detail as follows.

1. Widening

Wegerif (2010) defined *widening* dialogic space as increasing the degree of difference between perspectives in dialogue. In a classroom, the widening of a dialogic space can be enacted by soliciting different student ideas, encouraging students to elaborate more on their ideas, introducing new ideas, embracing a diversity of intellectual resources, acknowledging multiple ways of knowing, and incorporating students' language and experience into the classroom discourse, etc.

2. Deepening

Wegerif (2010) defined the *deepening* of dialogic space as increasing the degree of reflection on assumptions and grounds. The deepening of a dialogic space in a science classroom often looks like moving from surface observation to underpinning features of the phenomenon, examining evidence, constructing scientific reasoning, questioning the ontological and epistemological assumptions etc. The deepening function can be enacted by encouraging students to provide evidence for their ideas, unpacking their reasoning, and deconstruct their assumptions.

A helpful way to envision the deepening in science teaching is to use Grotzer (2002)'s typology of knowledge. According to Grotzer, there are three kinds of knowledge: procedural, conceptual, and structural. Procedural knowledge has a behaviouristic focus that learners can perform a procedure, such as dividing of a fraction is equivalent to multiplying its reciprocal (flip the fraction upside down). From my experience as a teacher, many students can perform this procedure and give the correct answer. Still, very few have the conceptual understanding of what it means to divide a fraction. This leads to the second type of knowledge, conceptual knowledge, which includes both declarative knowledge (knowing what) and knowing the connection between information to form a cohesive and meaningful mental model (knowing how and why). For example, we can understand evaporation as when water becomes water vapour. On a conceptual level, we can make sense of evaporation using a molecular model that evaporation is a process of energy gain and breaking of bonds from other water molecules. Conceptual understanding is robust because you can transfer the same understanding to make sense of other phenomena, such as condensation, dissolving etc.

Lastly, Grotzer (2002, p. 54) refers to structural knowledge as "connections at a more basic level for how we make sense of our experience; for instance, the way that one categorises, or how one attributes causality or characterises the nature of numerosity" as well as our epistemological and ontological assumptions. For example, when reasoning about causality in an ecosystem, children tend to focus on discrete events and adopt a simple linear cause-then-effect relationship. The deepening of dialogic space involves surfacing children's assumptions and having them question their assumptions about causality.

Using Grotzer's typology, the deepening of dialogic space can be thought of as moving from procedural to conceptual, conceptual to structural, and eventually deconstructing the structure and framing of knowledge so what is thinkable expands. For example, learning the scientific explanation for a ball falling involves having the procedural knowledge to compute velocity ($v=gt$), the conceptual knowledge about gravity (gravity as the force by which a planet or other body draws objects toward its centre), questioning the assumptions about the nature of force (e.g., a force can act without contact), understanding the contexts in which it applies when it breaks down, as well as our fundamental conceptualisation of gravity (e.g., force vs. curvature in the space) (Mortimer & Scott, 2003). It is important to note that the deepening of dialogic space is not linear because it is a cyclic process—as we question our underlying assumptions, we could go back to revise our initial ideas. For instance, after questioning the conceptualisation of gravity, students might revise their idea about the nature of gravity.

3. Maintaining

I define *maintaining* as signalling the ongoing nature of dialogic space (e.g., through words), which is often neglected in the structure of school and curriculum that tend to put an end to learning. We often use language such as 'wrapping up' a lesson and 'moving on' to a separate unit as if learning has ended, as the class is over. However, once a lesson, a unit, or a discussion is over, it doesn't necessarily indicate the end of the dialogic space. In fact, dialogic space continues, extends to the future, and includes voices that we do not yet know at the moment. In contrast to the conventional practice of wrapping up a lesson or a unit neatly and reaching a conclusion or agreement, dialogic education reveals the messiness and ongoing nature of learning and thinking.

Maintaining a dialogic space might look different at various stages of an inquiry. For example, at the beginning of an inquiry, maintaining could look like noting down different ideas in a shared space and making plans to further investigate. In the middle of a discussion, maintaining might look like juxtaposing different ideas in tension or revoicing student ideas and broadcasting it back to the class. At the end of a discussion, maintaining could be summarising what has been talked about and making plans about what are the next steps. Towards the end of a unit, maintaining could be asking students what they have learned and what questions they still have, and encouraging students to continue questioning and exploring further.

4. Shaping

Dialogue at a dinner table and dialogue at a science panel are different, though both can be fruitful. Shaping a dialogic space is to make visible the expectations and ground rules of the particular kind of dialogue that students engage in. By ground rules, I do not only mean rules of participation, such as taking turns and respecting each other. It also means making visible the practice of a discipline according to the standard of the community and the disciplinary ways to share their thinking (Ford & Forman, 2015; Resnick et al., 2018). In a science classroom, shaping a discourse could mean making it clear to students: what consists of scientific reasoning, how to support a claim with evidence, what counts as evidence, what consists of an explanation, and what it means to engage in scientific argumentation (Windschitl et al., 2018).

5. Initiating

Initiating is defined as teachers starting a new thread of discussion/ideas, which is often accomplished by open-ended/closed-ended questions. Both open/close-ended questions can be monologic and/or dialogic. For example, if a teacher asks students, "what is the colour of snow?" This seems to be a closed-ended question with "white" as the only correct answer. However, this question could make students wonder what whiteness actually is. What makes something white? Does what appears to me as white look the same for everyone and other animals? In this case, the closed question carries a dialogic function and opens possibilities for exploration.

6. Feedback

Feedback is defined as teachers' evaluation, feedback, or appraisal of the student's contributions. Similar to initiating, feedback is not intrinsically unproductive. Sometimes, it is important to evaluate the scientific rigour and quality of student arguments based on the disciplinary practice of science, such as in the case of misinformation. Other times, it is important to provide encouragement to students by giving them praises. Depending on the learning goal, teachers also can enrich the dialogic space by providing their own views and interpretations as feedback.

Though each dialogic function is distinctive in its features, they are often intertwined and entangled in practice. For example, the widening of a dialogic space can simultaneously lead to deepening as students reflect on the underlying assumptions of their ideas (Wegerif, 2011b). Maintaining a dialogic space by holding ideas can lead to deepening as well as generating new ideas.

2.4.5 Measuring Contingent Responsiveness

Measuring contingent responsiveness is challenging due to its complexity and multifaceted nature, i.e., improvisational, intellectual, technical, contextual, and relational.

Monologic Stance

Assessment of teacher responsiveness has been dominated by a monologic stance, meaning that researchers define responsiveness in advance and then try to locate it to teachers' practice, using a predetermined observational rubric (e.g., Lineback, 2015; Pierson, 2008). Indicators of responsiveness include the use of talk moves, such as eliciting a student's ideas and pressing students to elaborate. The most common approach is to compare the frequency of these desirable moves in the pre- and post-intervention assessment and/or rank the degree of a teacher's responsiveness from low to high (Pierson, 2008). However, such an approach is problematic, as it contradicts the essence of responsiveness, which has to be contingent on the everchanging needs of the situation. In other words, in dialogic teaching, a teacher's moves are not predetermined, but rather they are selected and invented in response to the situation at hand (Chazan & Ball, 1999).

Research with a monologic stance usually adopt a developmental scheme of responsiveness, assuming teacher's progress from a stage of not being very responsive, to gradually becoming more responsive (e.g., Empson & Jacobs, 2008). However, such stage-based accounts fail to explain the variability of 'teacher responsiveness' over multiple time scales (Lau, 2010; Levin et al., 2009; Russ & Luna, 2013). For example, Robertson et al., (2016) showed that a teacher could shift from being responsive to student ideas to being non-responsive within the short span of a few minutes in the same class. As it is implausible for teachers to develop the competency over the course of minutes, the stage-based account of progress is not a satisfactory model for a teacher's progress when learning to become responsive. Maskiewicz and Winters (2012) also challenged the developmental scheme for responsiveness, arguing that responsiveness is a complex dynamic, rather than a linear progression.

Assessing teacher responsiveness from a monologic stance using decontextualised indicators of responsiveness, and the linear model of progress do not take into account the dynamic, tacit and contextualised nature of CR. CR cannot be measured just by looking from the outside because CR is shaped by individual and contextual factors. Researchers do not have access to how teachers perceive and interpret the contextual factors (which sometimes often escapes the individuals as well), and that is why it is critical to take a dialogic chiasm approach.

The Chiasm Approach

Wegerif (2020) argued that the perspective of teachers moving from inside-out and the view of the researcher that is trying to define and locate that experience from the outside-in, are fundamentally incommensurable. These two views have to be combined in a dialogue rather than reduced to a single gaze. He calls the combination of an inside view looking out, and an outside view looking in as *chiasm* — a term borrowed by Merleau-Ponty from the field of rhetoric where it is used to refer to the reversibility of a subject and object in a sentence. Unlike triangulation, the chiasm approach proposes to bring the outside and inside view together, to allow inter-animation, and to gain new insights and meaning without ever fully integrating them into a single vision (Wegerif, 2020). The incommensurable gaze of the inside and outside is echoed by Mason (2016) that the interpretation of an observer might be in stark contrast to the teacher's experience. Also, different observers will also interpret things differently. Using a chiasm approach, CR can be measured by a combination of the researcher's view and participants' views. The researcher's view can derive from an observational rubric, and the participants' views can be accessed through a retrospective interview. These views are held in juxtaposition in the analysis to generate an augmented vision.

2.4.6 Summary

In Section 2.4, I defined CR and its granularity. The nature of CR is described as technical, improvisational, intellectual, contextual, and relational. In this study, science discussion is conceptualised as a dialogic space and CR is operationalised as widening, deepening, maintaining, and shaping the dialogic space. Finally, I discussed the problems associated with the monologic view in assessing CR and proposed a chiasm approach. In next section, I shift the focus towards discussing current professional development approaches in fostering teachers' adaptive expertise.

2.5 Teacher learning of adaptive expertise

2.5.1 Teacher expertise and tacit knowledge

Teachers' work is situated in a multidimensional space full of "blooming, buzzing confusion of sensory data" (Sherin, 2011, p. 4). Teachers have to make a large number of decisions very quickly and swiftly in the classroom (Dudley, 2013). For instance, as discussed earlier, within a short span of a one-minute 28-second, a math teacher counted 20 micro-moments where she had to make an instructional decision (Barshay, 2018). To cope with such a large amount of sensory data in the classroom, teachers have to establish routines and strategies in their long-term memory to automatise aspects of their practice. These become part of teachers' expertise and tacit knowledge, which is "deeply rooted in action, procedures, routines, commitment, ideals, values and emotion (Nonaka et al., 2000, p. 7)."

However, because such knowledge is deeply internalised, embodied, and automatised, teachers do not usually have conscious access to this tacit knowledge without deliberative efforts, such as via professional dialogue during lesson studies (Dudley 2013). Tacit knowledge, though extremely useful, could become problematic if left unexamined. For example, teachers develop a *professional vision* (Goodwin, 1994), a particular way of seeing and understanding classroom events, to decide what information to pay attention to and what to disregard. Without examining one's professional vision, teachers might not be conscious of missing out on important details about student learning.

Therefore, in teacher learning and PD, there needs to be a balance between establishing routines and shedding light on teachers' tacit knowledge. Without routines and tacit knowledge, teachers would not be able to cope with the overwhelming demands of the classroom. Without eliciting and examining tacit knowledge, it is difficult to change and improve one's practice. Adaptive expertise strikes such a balance between efficiency and innovation: the mastery of procedures in addition to the sensitivity to know when/how/under what condition to apply the skills, modify and invent new ways of doing in unpredictable situations (E. E. Baldinger & Munson, 2020; Schwartz et al., 2005). In Mason's words, teachers ought to "sensitise oneself so as to notice opportunities in the future in which to act freshly rather than automatically out of habit" (2011, p. 35).

This study is interested in supporting teachers to develop CR, an adaptive expertise to respond productively to the unpredictable flow of student talk in the classroom. The following section explores various tools in the literature that support the development of adaptive expertise.

2.5.2 Approaches that support the development of adaptive expertise

1) Video-based approach

Video is the most commonly used and inexpensive tool to support teachers to develop skills that are situationally dependent as it captures image, motion, and sound providing a contextually rich environment to analyse and reflect on aspects of teaching that cannot be captured by other media (Chan et al., 2020). Videos can be either an excerpt of a teacher's own teaching or recording of other teachers. Videos of one's own teaching are common in professional development. One of the most cited examples is Sherin and van Es's video club, where teachers meet to watch and discuss excerpts of videos from each other's class (Gamoran Sherin & van Es, 2009; M. Sherin, 2007). In teacher education, videos often used for modelling good teaching practice (The Argumentation Toolkit, n.d.) or as probes to elicit in-the-moment thinking and teachers' tacit knowledge (Chan & Yau, 2020).

Though video is a very important tool in supporting teachers to examine their practice and shed light on their tacit knowledge, it has its limitations to foster adaptive expertise. Video clips are not responsive to the decision making and teachers cannot experience the consequences of their decisions. Decision-making through video clips are discrete events ending with a finite response. On the other hand, in a real classroom, decision-making is a chain of events – a response will trigger other events. Therefore, videos are very useful in eliciting 'slow thinking' to unpack a particular moment in the classroom and/or a pedagogical dilemma, but it is limited in its ability to simulate the fast-paced nature of a real classroom and in evoking decision making in real time.

2) Lesson studies

The lesson study approach originates from Asia and has been adapted in various cultural and teaching contexts around the world (Stigler & Hiebert, 2016). In general, lesson studies involve small groups of teachers who collectively identify an area of improvement in their practice, design a research lesson, teach, and observe the research lesson, and thoroughly review the research lesson in an open discussion to refine the research lesson in multiple iterations (Godfrey et al. 2019, Dudley 2013). The knowledge produced during the lesson studies is publicly shared among colleagues via short papers, presentations or ‘open house’ lesson (Dudley, 2013). Lesson studies have the affordance to ‘slow down’ the fast-paced classroom and give teachers access to their tacit knowledge by inviting multiple teachers to examine, elaborate and discuss a particular detail in a lesson. Such close examination not only helps teachers to shed light on their own tacit knowledge but also see alternative possibilities from multiple perspectives, allowing teachers to develop new practice.

3) Simulations

According to Kaufman and Ireland (2016), simulation is a form of situated learning and provides a contextually rich environment for learners to problem solve, experience the consequences of their actions, and modify their actions in a low-stakes environment. Although simulations are not necessarily mediated through digital technologies, computer-based simulation has gained popularity for its cost-effectiveness and scalability. Three examples of computer-based simulations are presented below: simSchool, Second Life, mixed-reality simulation (e.g., Mursion).

simSchool

simSchool is a web-based classroom simulation, where players select instructional tasks, management strategies, and conversational exchange from a menu (see Figure 2.3). The simulated students respond to instructions by raising their hand, showing signs of emotions, or giving text-based responses. For instance, the student is showing signs of disengagement in Figure 2.4, and the player is clicking on her to select an intervention. Each simulated student has a unique profile; players can differentiate their lessons and give personalised instruction. simSchool intends to simulate the complexity of a real classroom and support players to practice decision making with repeated practice and to experiment with alternative strategies. simSchool operates on a computer algorithm, which makes it suited for private asynchronous practice (Meritt et al., 2013). While simSchool is capable of eliciting rapid decision making, teacher actions are restricted by predetermined options, which does not represent the flexible and adaptable nature of contingent responsiveness.

Figure 2.3 A menu of instructional tasks in simSchool (simSchool Educator Training, 2020)

Photo of instructional tasks in SimSchool interface removed for copyright reasons.
Copyright holder is simschool.org/

Figure 2.4 A student in simSchool showing signs of disengagement (SimSchool, n.d.)

Photo of SimSchool classroom removed for copyright reasons.
Copyright holder is simschool.org/

Second life

Second life is a multi-user interactive virtual environment (Ma et al., 2016). Virtual worlds can provide any experience that a user wishes to create, e.g., a game experience, educational experience etc. Second life has been used to construct a virtual classroom to provide a virtual teaching experience for novice teachers, see

Figure 2.5. The virtual students are role-played by peers without necessarily being in the same geographic location. Software (robot) can be used to fill a classroom when there are not enough human participants (Mahon et al., 2010). Second life allows the entire class to participate simultaneously by taking on different roles, which facilitates co-construction of knowledge as a community (Meritt et al., 2013). However, Mahon et al., (2010) found that recurring technical glitches made the simulation experience less authentic and smooth for participants. Muir et al., (2013) reported that controlling avatars with fluency seems to be a challenge for many participants which affected their ability to role-play. These issues significantly limit the capability of Second Life to elicit in-the-moment thinking from teachers.

Figure 2.5 A science class in Second Life (Mahon et al., 2010)

Photo of Second Life classroom removed for copyright reasons.
Copyright holders are Jennifer Mahon and colleagues (2010).

simSchool and Second Life are useful for different pedagogical purposes in teacher education. The role-playing system in Second Life creates a shared space for the construction of pedagogical knowledge synchronously, whereas simSchool simulates the complexity in a classroom and elicits rapid decision-making in asynchronous settings for individual practices. Nevertheless, they are not ideal for the development of CR. simSchool limits the options of a teacher's response, which does not reflect the flexibility and adaptability of contingent responsiveness. The technical difficulty in Second Life does not allow users to role-play with fluency, which inhibits the authenticity of the simulation. In the following section, I introduce mixed-reality simulation and unpack how it operates and its affordances.

2.5.3 Mixed-reality simulations (MRS) as an emerging technology

2.5.3.1 What is a mixed-reality simulation?

Mixed reality is the juxtaposition of virtual and real environments, which imitates a real-life scenario. The juxtaposition of the virtual and physical environment creates a spectrum of mixed realities, ranging from augmented reality to augmented virtuality, as illustrated in Figure 2.6 (Milgram & Colquhoun, 2001). An augmented reality occurs when a computer-generated object is superimposed into the physical world, whereas augmented virtuality happens when a real-world image is superimposed into a virtual environment. The type of mixed-reality technology in this study, Mursion®, aligns closer to the augmented virtuality side of the spectrum (Gundel et al., 2019). Mixed-reality has been applied in many fields, such as the military, healthcare and transportation (Banks, 1998), whereas, its application in teacher education and teacher professional development is only recent (Dieker et al., 2014).

Figure 2.6 The Reality-Virtuality Continuum (Milgram & Colquhoun, 2001)

Figure of the reality-virtuality continuum removed for copyright reasons.

The copyright holders are Paul Milgram and Herman Colquhoun.

2.5.3.2 Mixed-reality simulation

The mixed reality simulator, Mursion® (formerly known as TeachLivE), used in this study was initially developed by a team of educators and computer scientists in the University of Central Florida. Mursion, a start-up company based in California acquired the rights to TeachLivE, intending to scale up the technology.

During Mursion simulations, participants engage with the digital avatars in front of a screen in a physical environment (see Figure 2.7) or in a virtual environment via video conferencing (e.g., zoom) (See Figure 2.8). Using a combination of artificial intelligence and trained simulation specialists (human in the loop), the interactions between teacher participants and avatar students in Mursion are authentic and similar to what they would experience in a real classroom. The role of a simulation specialist can be thought of as digital puppeteer. All student avatars (usually five) are controlled by a single simulation specialist, each with his/her unique voice, gestures, and personality. In a simulation, teacher participants can teach lessons, manage the classroom, and practice their pedagogical skills before entering a real classroom. It is important to note that the purpose of Mursion is to develop teaching expertise in a scaffolded environment before enacting them in a real classroom, thus, to complement and reinforce practicum rather than to replace it.

Figure 2.7 A teacher interact with student avatars in front of a screen (Rimel,2020)

Photo of a teacher interacting with avatar students in front of a TV screen removed for copyright reasons. Copyright holder is Anthony Rimel, Western Oregon University

Figure 2.8 A teacher in this study interacting with avatar students via zoom

2.5.3.3 Affordances of Mixed-reality simulation for developing CR

Mixed-reality simulation (MRS) has unique affordances to support teachers in developing adaptive expertise, such as CR:

1) Contextualisation

Mixed reality not only supports teachers to hone specific pedagogical practices (routines, techniques, strategies, etc.) through repeated practices, but it also provides a contextualised environment for teachers to exercise their professional judgement.

2) De-composition and re-composition of practice

Osborne (2015) raised the question of whether we have been asking teachers to run before they can walk. He argued that mastering a complex skill requires deliberate practice of specific and focused tasks, equivalent to learning to play common scales on a piano. CR can be decomposed into manageable granularity to allow teachers to focus on the targeted dimension of the classroom. On the other hand, MRS supports re-composition, integrating parsed skills into a complex practice.

3) Slowing down the action

MRS can slow down the fast pace of a real class for teachers by allowing them to pause the simulation at any moment to reflect before acting. Also, simulation can open up the compacted 'micro-moments' into expansive 'dialogic space' for teachers to collectively examine their decision-making and challenge their existing practice and produce new knowledge and understanding.

4) Switching frames of references

MRS affords participants the opportunity to shift between exocentric (outside of the simulation) and egocentric (inside of the simulation) frames of reference. The egocentric perspective enables participants to take on the role of the teacher and engage in embodied learning, whereas exocentric perspective allows participants to distance themselves from the context and to reflect on the actions taken (Dede, 2009).

2.5.3.4 Limitations

Technological artefacts can be viewed as a mediating cultural tool with particular affordances and constraints—they can promote certain types of actions while inhibiting others (Hennessy et al., 2018). Thus, I would like to acknowledge the limitations of using MRS to support teachers in developing CR.

1) The tension between a closed simulation and an open dialogue

While there is space for improvisation, a simulated scenario is scripted beforehand; it is a relatively closed space compared with genuine dialogue in a real class. Is simulation the antithesis to dialogic teaching in principle? Depending on how the simulation scenario is designed and how it is used in a larger context of an instructional design, it can either function as a drill for routine expertise or as a vehicle of contextualisation to develop adaptive expertise. Therefore, the simulation scenarios in this study are highly contextualised, drawing on teachers' real-life experience in the classroom and the literature to approximate the complexity of dialogic teaching practice.

2) Genuine relationship building

Relation building between teachers and students and among students is paramount in dialogic teaching (Wegerif, 2013). Is it possible for teachers to feel a sense of connection with the avatar students? In Mursion, avatars are blended in with a human in the loop, thus, the interactions between teachers and avatars are essentially human interactions. Therefore, powerful emotional responses can be induced (Llobera et al., 2013; Martini et al., 2014). Relationship building with avatar students was highlighted in the mixed-reality simulation intervention developed by the Reach Every Reader program (Reach Every Reader, 2020). Also, feedback from users indicates success in the suspending of disbelief during MRS (Dawson & Lignugaris/Kraft, 2017; L. Dieker et al., 2014). As the application of MRS to teacher learning is relatively new, this study seeks to test these claims whether teachers can develop a sense of connection with avatars students.

2.6 Research questions

In this chapter, I reviewed the importance of dialogue in science teaching, not only as a means of learning, but also as a goal in and of itself. I also showed that the heart of dialogic teaching is contingent responsiveness, by responding to students in the moment to widen, deepen, maintain, and shape dialogic space to promote collective sense-making and equity in the classroom. So far, little is known about how teachers develop such adaptive expertise and the features of effective PD. Mixed-reality simulation as an emerging technology has unique affordances to approximate the complex and dynamic nature of a classroom, enabling teachers to embody dialogic teaching and reflect in a scaffolded environment in real-time. It is important to note that MRS is positioned as one component of the whole ecosystem of PD, and it is interwoven into the fabric of the PD design. Therefore, this study does not seek to test the effectiveness of MRS on its own, rather it aims to leverage the technology to tackle the challenge of fostering CR in dialogic teaching.

In summary, this research aims to leverage emerging technology (i.e., mixed-reality simulations) to:

1) Co-design an effective professional development (PD) programme with the practitioners that supports teachers in developing CR.
2) Understand the mechanisms of the PD that allow teachers to develop CR.

Research Question 1: To what extent were teachers contingently responsive to students during science discussions before and after the PD?

Research question 2: What are the mechanisms that support teachers in developing contingent responsiveness?

Chapter 3 Methodology

This chapter critiques the monologic causal model in education research, identifies the key characteristics of design-based research (DBR), describes the research context, and explains the rationale for choosing DBR as a method for this study. Finally, I outline the research design and three phases of this DBR study.

3.1 Why 'what works' doesn't work?

Educational research has long been criticised for being descriptive in nature and having little impact on improving educational practice. One attempt to bridge the gap between research and practice is to find 'what works' through experiments and randomised controlled trials.

Wegerif et al. (2020) argued that such a monologic causal model which assumes that input A is going to lead to output B is inappropriate considering the complexity of learning and class environment. Similarly, Lefstein et al. (2020, p. 10) asserted that "practices, norms, and structures are complex, interlocking, and situated; how any given element functions cannot be separated from its interactions with other elements, and isolating one element as 'effective' is unlikely to produce the intended results." Furthermore, Taber (2019) raised the potential threats to the validity of findings from randomised controlled trials (e.g., novelty effect, participant expectation, testing effect, etc.), not to mention ethical concerns when students in the control group are expected to be disadvantaged compared to those in the experimental group.

An intervention that works in one context does not necessarily transfer to another one (Hennessy et al., 2015; Lefstein et al., 2020). Reeves (2006) argued that even if the results of predictive research could demonstrate the efficacy of educational technology, translating those findings into practice is not a given. Taber (2019) maintained that experiments can tell us at most whether something works but cannot inform us of how and why it works. Without knowledge of critical features and mechanisms of change, it is often difficult to transfer to a different context and to scale (Osborne, 2015). Furthermore, the agency of teachers and students is usually left out of the equation as teachers and students are expected to apply 'what works' without considering their specific circumstances.

The 'what works' approach to research is underpinned by a monologic view that takes the existing goals of education as a given while trying to find the most effective way to reach them. Biesta

(2007) argues that the role of research is also to provide new understandings of educational reality and different ways of imagining the future of education. In other words, education research should not only focus on the most effective ways to achieve certain ends, but also continue questioning and reinventing those existing practices and tools.

In the context of teacher education and PD for dialogic pedagogy, the "what works" approach to research has not been particularly fruitful (Hennessy & Davies, 2020). Firstly, controlled studies on programmes in dialogic teaching are extremely hard to engineer in the real world of schools and tend to be characterised by a short timescale, limited sample size, limited range of outcome measures, and a lack of robust experimental design. Secondly, existing studies have rarely adequately identified, measured and considered potential confounding factors, which makes it difficult to isolate the impact of a particular aspect of dialogue on learning outcomes (See Howe et al., 2019 as an exception). As a result, the findings are mixed, and it is often difficult to know how and why any learning outcomes or changes in practices have been achieved (Hennessy & Davies, 2020).

Many educational researchers have realised the importance of moving beyond the simplistic narrative of "what works" to find out how and why an intervention works, so lessons can be learned by various stakeholders and to make an analytical generalisation (Yin, 1989). Hofmann (2020) encourages research to explain generative mechanisms that can bring about change—to understand how an intervention has an effect and why it may or may not lead to change.

3.2 Beyond what works: Design-based research (DBR)

In the early 1990s, design-based research (DBR) stemmed from the desire to bridge the gap between research and practice by taking into account the complexity of learning and employing iterative designs and collaboration between researchers and practitioners. Gravemeijer and Cobb (2006) explained that the overall goal of such an approach is not to assess whether something works, although the researchers will necessarily do so, but to both test and improve the conjectured local instructional theory that was developed in the preliminary phase, and to develop an understanding of how it works. In other words, DBR seeks to understand not only whether an intervention/program works, but also how it works. In the following section, I summarise the key characteristics of DBR.

3.3 Key features of DBR

1) Dual-function: theory building and practical innovation

The defining characteristic of DBR is its dual function of developing theories and producing usable knowledge in the form of design (Bakker, 2018; Cobb et al., 2003; A. Collins, 1992; McKenney & Reeves, 2012; Van den Akker et al., 2006). In DBR, design is guided by theory, and theory is refined through iterative design cycles (Wegerif et al., 2020). In DBR, a theory has to do real work (Cobb et al., 2003), which means theory alongside craft wisdom and creative inspiration is used to construct solutions to solve real-world problems, which makes DBR interventionist in nature.

2) Understanding learning within the natural setting with practitioners

The traditional paradigm of educational research focuses on experimental control and isolating variables (Lagemann, 2002). Such research has low ecological validity—producing scientific sound claims but insufficiently to make explanations or predictions in the natural setting where the phenomena occur. Design-based research attempts to address ecological validity by conducting research in places where learning actually takes place and treating learning as an integral and meaningful phenomenon instead of isolated variables (Van den Akker et al., 2006).

Traditionally, educational practitioners (e.g., teachers and administrators) are the subject of research and are excluded from the research design process. Nonetheless, solving real-world problems requires collaboration among a range of actors and stakeholders. DBR, therefore, values the ground level instincts and craft wisdom of practitioners, and research is often conducted in collaboration with practitioners (McKenney & Reeves, 2012).

3) Cyclic and iterative nature and flexibility

DBR is characterised by its cyclic, iterative nature and a progressive refinement approach (A. Collins et al., 2004). The design evolves over multiple iterations, involving formatively testing a prototype in its natural environment and multiple revisions until the outcomes are deemed to be satisfied. Interim testing can be done frequently and the findings will inform the design (Bransford et al., 2000). Such an approach is efficient in that we can update the design as needed instead of waiting until the end of an experiment.

Real-world issues are usually complex, so the design cannot be conceived at the drawing table alone (van den Akker, 1999). DBR is adaptive in nature allowing room for surprises (Bakker, 2018). The flexible nature of DBR allows researchers to make adjustments and fine-tune the design after each iteration, which increases the robustness of the design and offers a better chance of creating an intervention that is effective and viable.

4) Pragmatic philosophical underpinning

DBR is committed to create impactful change with the participants in local research site. DBR researchers mostly subscribe to a pragmatic philosophical underpinning – the value of a theory lies in its ability to produce changes in the world (Barab & Squire, 2004). Therefore, DBR studies are not merely research projects, but also vehicles for change.

3.4 Research Context

3.4.1 The search for research sites

Finding a research site during the pandemic was challenging. This research initially was planned to partner with a teacher education program in the Boston area during my visiting fellowship at the Harvard Graduate School of Education (09/2020-09/2021). The pandemic disrupted the original research plan since I could not travel to the US and secure a research site in Boston. The pandemic has caused significant disruption in people's work and life, which was one of the reasons why people are less likely to engage in new research projects at this time. I have also sought collaboration with Linkoping University in Sweden, which had experience in conducting research with mixed-reality simulations. At the same time, Harvard Graduate School of Education moved its entire teaching online, which allowed me to conduct my visiting fellowship remotely. In one of the virtual classes, I met Ms Jaweria Sethi, a school leader in Pakistan pursuing a Master of Education. Upon explaining my research plan to her, she was interested in having her school participate in this study. After a discussion among the school leadership team, the school decided to collaborate with me on this research project.

Below I first outline the education landscape in Pakistan in general and then zoom into the school context. I reflect on my positionality as a researcher, the ethical considerations, and my rationale for conducting the research at Edopia School in Pakistan.

3.4.2 Educational landscape in Pakistan

Pakistan, as a developing country, is facing challenges in education access and quality (Amir et al., 2020; Richter, 2019). In terms of access, an estimated 22.8 million children aged 5-16 are out of school (UNICEF, 2020). 27% of primary school-aged children are not enrolled in school (World Bank, 2019). In terms of quality, there is a lack of qualified teachers in the country and a limited number of teacher education programs (Ahmad et al., 2014). The existing education programs are often poorly structured, using outdated curricula with limited opportunities to develop competency and effective teaching practice. There is also a lack of system established for in-service teacher professional development (Ministry of Federal Education and Professional Training, 2017)

Student achievement remains low in Pakistan (Ministry of Federal Education and Professional Training, 2017). 75 % of children in Pakistan at late primary age today are not proficient in reading, age-appropriate text, which is 16.3% below the average for the South Asia region and 19.5% below the average for lower-middle-income countries (World Bank, 2019). According to the most recent scan conducted by the EdTech Hub, education in Pakistan suffers from insufficient funding, infrastructure, qualified teachers, and clear policy and governance).

There are three types of schools in Pakistan (Baloch & Abeba Taddese, 2020):

- Public schools which follow the national curricula
- Private schools that either follows the national curricula or the Cambridge examination system
- Deeni Madrassas (religious seminaries) that teach the curriculum of Wifaq-Ul-Madaris, which is the largest federation of Islamic Seminaries in Pakistan

Private schooling is an essential component of the education system in Pakistan (Andrabi & Das, 2002). One-third of students attend private schools in Pakistan (Nguyen & Raju, 2014). Contrary to general perception, the majority of private schools in Pakistan are affordable because of their low operating costs. Many private schools are staffed by young, unmarried women with a low level of education who are paid substantially less than teachers who work in government schools (Nguyen & Raju, 2014). According to Waqas Halim, a researcher from Pakistan at EdTech Hub (personal communication, October 28, 2020), public and private schools suffer from poor quality of education with very few exceptions. The quality of private schools varies largely depending on tuition, which ranges from approximately \$9-\$300 monthly (Jaweria Sethi, founder of Edopia, personal communication, Oct. 17, 2020).

3.4.3 School Context

Edopia school is the first democratic private school in Pakistan, established in 2014 and located in the capital city, Islamabad. The school currently has 260 students from pre-school to grade 11[1]. It is inspected biannually by the Private Educational Institutions Regulatory Authority (PEIRA)[2], the authority that grants registration certification to educational institutions operating in Islamabad. The goal of Edopia school is to provide high-quality education and an alternative learning experience. The language of instruction at Edopia School is English. However, learners speak their local dialects at home.

3.4.3.1 Approach to Education

Unlike a traditional top-down approach, Edopia school encourages learners to take charge of their own learning by giving them choices and agency. Learners have the choice to construct their own timetable and select subjects according to their interests and passion with the guidance of the teachers, parents, and school. Coursework includes cores and electives. Core classes include numeracy and 'units of inquiry', an interdisciplinary class covering literacy, science, and social studies. For numeracy classes, Edopia uses the Singaporean curriculum for Grades 1-6 and the Cambridge curriculum for Grade 7-11. For 'units of inquiry', Edopia uses the Cambridge curriculum from Grade 1 to 11. Teachers use the curriculum as guidelines and do not necessarily follow the content. The class size of core classes is usually below eight students per class. Every student is encouraged to take core classes, although they are not mandatory. The elective courses are subject-specific and expert-guided (e.g., programming). Elective classes are structured based on learners' interests which may or may not follow an external curriculum. Learners also have free periods during the day, which they choose how to use (e.g., getting extra help with a subject, working on a group project, quiet reading, independent studies, meeting with a mentor, play with peers).

[1] Pre-school: age 3-5
Elementary: age 6-9
Middle school: age 10-13
O levels: age 14-16

[2] https://peira.gov.pk/

3.4.3.2 School socioeconomic status (SES)

To keep the class size small (maximum at 8), to provide time and space for teachers to plan innovative lessons and improve their practice with good remuneration ($300/month), the tuition fee at Edopia school is at the more expensive end of the spectrum among private schools, currently charging each student $200/month. 25% of the students have scholarships or financial aid, and the rest come from upper-middle and high socioeconomic backgrounds.

Edopia school has better infrastructure and more resources than most public and private schools, but the principle of the school is to not establish an elite school. Rather, the school serves as a prototype of alternative schooling in Pakistan, which is community-based and student-driven. The school has an ambitious vision to create a model that empowers and upskills community members to run their own school within their local community. The school also aims to evolve a financial model that can eventually offer free tuition for students coming from low-income families using fees from tuition-paying students, which they call 'one child pays for another'. Before the pandemic, Edopia School reached out to the rest of the local community by welcoming children from nearby public schools to participate in their after-school programs.

3.4.3.3 Teachers and professional development

Teachers at Edopia are hired based on their competence, experience, and potential rather than credentials. Most of the teachers do not have formal teacher training. Edopia provides initial training to new teachers and ongoing mentoring as they start to teach. Four teacher coordinators are veteran teachers at Edopia and mentor the rest of the teachers. Teacher coordinators do not have their own classes, and their primary responsibilities are to supervise the day-to-day function of the school and mentor/coach other teachers. Teachers either teach at the pre-school (early years), elementary or secondary levels. Teachers at Edopia have participated in PD related to cultures of thinking[3], thinking routine[4] from the Harvard Zero Project, and worked with a consultant Robin Duckett (Sightlines Initiatives) from the UK.[5]

3 http://www.pz.harvard.edu/projects/cultures-of-thinking

4 http://www.pz.harvard.edu/thinking-routines

5 https://www.sightlines-initiative.com/our-work/the-organisation

3.4.4 Teacher participants

Science is taught through an interdisciplinary approach called 'units of inquiry', including literacy, science, and social studies. 13 'inquiry teachers' from the early years, elementary, middle school, and O level (student age ranges from 6 to 16) initially participated in this study. Though the teachers did not necessarily have certification in teaching, they bring rich academic backgrounds in a variety of disciplines, such as anthropology, business, design, and art. All 13 teachers were female. Seven teachers were new to the school, and it was their first-time teaching. The school experienced a very high attrition rate during the pandemic. Eight out of thirteen teachers left the school during the pandemic (mainly early years teachers due to the difficulty in conducting remote learning for pre-school children). Four teachers followed through the entire DBR process of four iterations. Three Grade 1 teachers provided complete pre- and post-PD classroom recording at the end of study (student age from 6-7 years old).

3.4.5 COVID-19 restrictions

The school was closed due to the COVID situation and reopened its door in October 2020. However, half of the parents opted for remote learning for their children while the other half chose face-to-face learning. The school fully re-opened in August 2021. This study took place from December 2020 to February 2022, so half of the DBR took place during lockdown when teachers individually joined remotely from home, and the other half with teachers back on campus.

3.5 Research rationale

Edopia school is unique in the education landscape of Pakistan, and simulation is a relatively new and costly technology. The cost-effectiveness of the technology needs to be significantly improved before it can be implemented at scale in LMIC contexts. Therefore, why research the use of sophisticated new technology in a unique school? What kind of impact can this research generate?

First of all, as discussed earlier, the Pakistan education system suffers from low-quality, inaccessible teacher education programs and a lack of opportunities for PD. For example, my meeting with Waqas Halim, a researcher in the EdTech Hub from Pakistan, revealed that many female teachers have no means to attend teacher education or PD as it is uncommon in the culture for women to travel alone (personal communication, Oct. 28, 2020). While simulation is at its early stage of application in teacher education and it is not yet cost-effective at a large scale, a number of studies have demonstrated the promise of simulation to support teachers to improve their teaching practice in the context of the global North, such as in the US _. In the long run, simulation can potentially be incorporated into teacher education programs at scale to make teacher learning more practice-centred and accessible. Research has repeatedly shown that implanting technology is not sufficient to improve the quality of education in LMICs (e.g., Beg et al., 2020). After systematically reviewing 170 studies on teacher professional development and educational technology in LMIC, Hennessy et al. (2022) reinforced the conclusion that successful PD is designed with and for teachers. This study addresses the predominant but inequitable focus of research on mixed-reality simulation to date in the global North by working directly with teachers in Pakistan, to understand the application of mixed-reality simulation in the context of an LMIC and include practitioners in the design and implementation of a technology-enhanced PD.

Edopia school is not representative of schools in Pakistan, yet it provided an ideal testing ground for this new technology in the cultural context of Pakistan. Studying new technologies in LMIC contexts is important to ensure that adaptability is engineered into the technology at its early stage of inception and application. This research does not aim to test the effectiveness of simulation technology, and rather it attempts to learn about the design considerations to leverage these in the context of an LMIC. Secondly, on a school level, this research project can help to strengthen the teacher induction program and PD in Edopia. As the founder explained, teachers do not usually have degrees in teaching, and they usually learn through a short induction program that consists of working with a coach and learning on the job. This study supported the teachers to improve their practice and contribute to the collective knowledge of the school.

3.6 Research design

This study sought not only to design a PD programme for contingent responsiveness in dialogic teaching and test its effectiveness, but also to contribute to the learning theory of how teachers develop such adaptive expertise and to uncover the mechanisms of the PD that led to change.

DBR is usually organised into phases (Herrington et al., 2007; McKenney & Reeves, 2012). This study was organised into three phases:

Phase 1: Understand the design context, identify high-level conjectures (i.e., design principles), and outline initial conjecture map (See Chapter 4)

Phase 2: Co-design with practitioners, four iterative implementations, and formative assessments (See Chapter 5)
Phase 3: Summative evaluation, reflection, and dissemination (Chapter 6, 7, 9)

The PD design embodied the improvisational, technical, intellectual, contextual, and relational nature of contingent responsiveness (Cao, 2021). The PD program had two components:

1) **Collaborative workshops**, where teachers engaged in collaborative and guided inquiry, collective reflections to develop conceptual understanding of dialogic science teaching, and to learn about various talk moves (Michaels & O'Connor, 2012).
2) **Simulation sessions,** in which teachers put into practice their learning from the workshops by orchestrating a science discussion in a virtual classroom with avatar students, just as a pilot learns to fly a plane in a simulator (Dieker et al., 2013).

The details of the design process and iterations are explained in Phase 1 (Chapter 4) and Phase 2 (Chapter 5) of the study.

3.7 Ethical considerations

This research was conducted in accordance with the ethical guidelines of the British Educational Research Association [BERA] (2018) and the guidelines of Edopia School. To ensure the safety of all participants during the COVID-19 pandemic, this study was conducted remotely through zoom meetings. There were three groups of participants involved in this study: teacher coordinators, teachers, and students (who are represented by their parents).

Participant consent forms (see Appendix 1) were distributed. Participation in this study was voluntary, and performance in the study was only evaluated for research purposes. The school leadership team was not allowed under any circumstance to evaluate the job performance of the participant using the result of the research. All participants were asked for written consent to this study and class discussion video recordings before the study began.

The classroom videos shared by teachers/teacher coordinators were directly uploaded to the OneDrive of University of Cambridge and stored for 10 years before being permanently deleted. Participants were anonymised when reporting the results. Participants were free to withdraw their participation at any time and without giving a reason. After withdrawal, all data related to the individual participant were destroyed unless it was collected in a group setting.

3.8 Summary of the chapter

I started this chapter by critiquing the problems in a monologic causal model in education research and introduced the key characteristics of DBR: 1) dual function of theory building and practical innovation, 2) understanding learning within the natural setting with practitioners, 3) cyclic and iterative nature and flexibility, and 4) pragmatic philosophical underpinning. I introduced the overall landscape of education in Pakistan and the unique research context in Edopia school, an ideal place to study MRS as an emerging technology in the context of LMIC, addressing the predominant but inequitable focus of research on new technologies in the global North. I finished the chapter by outlining the three phases of the DBR. In the next chapter, I discuss in detail Phase 1 of the study, explaining the design context, identifying high-level conjectures (i.e., design principles), and outlining the initial conjecture map.

Chapter 4 Phase 1: Understanding design context, identifying high-level conjectures, and initial conjecture map

Phase 1 of the DBR focused on gaining an in-depth understanding of the local context and identifying a set of high-level conjectures in the literature to guide the overall design. An initial conjecture map was produced based on a literature review on how teachers could develop CR. A set of design and theoretical conjectures were then proposed, which were further adjusted and refined across four iterations. Finally, I reflected on my positionality as a researcher and designer at the end of this chapter.

4.1 Understanding the design context

To understand my design context, I approached it at three levels. First, to develop an understanding of the general educational context in Pakistan, I consulted literature and spoke to local researchers outside of the school context. At the same time, I worked as a research assistant at the EdTech Hub, conducting a systematic review of teacher learning and educational technology use in LMICs. Through my work at the EdTech Hub, I benefited from having access to detailed country scans (e.g., Zubairi et al., 2021) and connecting with colleagues with experience of working on the ground. To understand the local school context, I spoke regularly with the founder of the school in addition to meeting the school leadership team. Finally, to understand teachers' practices, I met with each teacher individually before the PD to get to know them. Each teacher shared a video recording of their class discussion with me, introducing me to their groups of learners, the class context, as well as their thinking and planning underlying the discussion. These interviews and conversations formed the foundation of the PD design. It is important to note that all the class discussions took place in a zoom environment, which was not necessarily representative of how children behave in the face-to-face environment.

Here I highlight important considerations of the design context gleaned through the above activities:

1) As the country's first democratic school, the school is unique in the education landscape of Pakistan. The school is founded upon the democratic principles of voice and choice. The voices of all school members are heard in democratic assemblies and choices are made via voting. Furthermore, the school adopts a personalised-learning approach, in which

children have choices in making their own timetables, with the exception of core subjects. Finally, small-group coaching is prevalent at the school as an educational approach.

2) The school is well equipped in terms of educational technology and resources in general, e.g., projectors, laptops etc.
3) The school values local knowledge and language, and students take Urdu and Islamic studies as part of the school curriculum.
4) Though many teachers did not have a teaching background, they brought in a variety of expertise and experience in other academic disciplines, such as anthropology, business, arts, and design. Seven of the thirteen participating teachers were new to the school, and it was their first-time teaching.
5) The school has a strong commitment to child-centred education and a constructivist approach to learning. Teachers share the commitment to foreground student ideas in their teaching, but there were various interpretations among teachers of what constructivism means in practice. Some teachers focused on children's ideas and imagination rather than the science content. Some teachers tried to achieve a balance between the science content and student thinking.
6) Teachers' understanding of science discussion varied; many of the pre-PD discussions were interactive lectures. Classroom talk was often characterised by the IRE/IRF pattern.
7) Students were generally active during the class. Most of the classroom talk was mediated by the teacher, and students did not often respond to each other's ideas. However, teachers mentioned that students collaborated more intensively during hands-on projects (which was not possible in a zoom class).
8) Some teachers were nervous about my opinion. I was conscious of my position as a researcher and the impact it might have on how teachers perceive the PD program (see my reflection in Section 4.5). I communicated clearly to the teachers that the discussion video was for me to learn from them and understand their teaching context rather than to evaluate their performance.

4.2 Literature review and high-level conjectures

Sandoval's (2004) high-level conjecture is close to a design principle, which provides the overarching guidance on how to design a learning environment. Sandoval chose to use the term 'conjecture' here instead of "principle" to connote the highly provisional nature of the ideas we have about how to design a learning environment at the start of DBR, whereas the hypothetical nature is implicit in the term 'principle' (Bakker, 2018). Such high-level conjecture is then embodied in a design. I chose to use the term "high-level conjecture" instead of design principle to avoid confusion surrounding design principles, which could mean value, ethical norm, criterion, guideline, heuristic, advice or prediction (Bakker, 2018). Identifying high-level conjectures is the first step after understanding the local context because it serves as overall guidance to shape the rest of the PD, such as determining design features. Gröschner et al. (2015) illustrated the importance of evidence-based design features (which they referred to as design components) in designing PD programs, which not only enhanced teachers' satisfaction and motivation but also ensured the effectiveness of the PD.

The high-level conjectures were primarily informed by literature on PD, especially PD related to the quality of classroom interaction (e.g., Borko, 2004; Dudley, 2013; Gröschner et al., 2015; Grossman, 2018; Hennessy et al., 2015; Hennessy & Davies, 2020; Lefstein & Snell, 2013), and by cognitive science literature (Brown et al., 2014; Glass, 2016; Kahneman, 2013). Integrating effective design principles of PD and the nature of CR, four high-level design conjectures emerged from the literature, which informed the overall design of the workshops and simulation sessions.

4.2.1 High-level conjecture for the workshops

1) Inquire with teachers rather than prescribing solutions

Successful PD programmes centre around teachers' agency and are grounded in the realities of teachers' daily work (Reznitskaya & Wilkinson, 2015). Hennessy et al. (2016) illustrated how teachers from low-resourced primary schools in Zambia transformed their teaching practice with the support of a PD programme that is centred around teachers' agency, positioning teachers as professionals capable of critiquing and developing their practice (also see Haßler et al., 2015; Hennessy et al., 2015). Similarly, Mason (2002) maintained that PD is not something we do to other people, but that it is a process of transformation of the self. Hennessy et al. (2011) created and refined an innovative model of PD called 'dialogic co-inquiry' that promotes equitable collaboration between university researchers and classroom practitioners. The co-construction of dialogic pedagogy is dialogic in itself as teachers and researchers build on each other's ideas to advance knowledge of professional theory and practice. What is unique about this model is that researchers did not present prescriptions to teachers but rather empowered teachers to make sense of the dialogic approach by critiquing the theory from exemplars of the classroom, their personal perspectives, and teaching experience. Drawing from Hennessy et al.'s (2011) dialogic inquiry model of PD, my overall design centred around teachers' agency to develop understanding and make meaningful connections to their own teaching practice and context. Therefore, throughout the PD, I worked closely with teachers in their teaching context. The PD focused on providing teachers with tools and opportunities for dialogue and reflection rather than prescribing solutions.

4.2.2 High-level conjectures for the simulation sessions

1) Combine fast and slow thinking

According to Kahneman's (2013) dual-system theory, most of our actions are driven by habits instead of careful consideration. Having habitual reactions is necessary as otherwise we would not be able to cope with the myriad of stimuli we encounter, but it can get in the way of making better decisions.

Currently, there are two main approaches to 'teach' responsiveness. The first approach foregrounds 'fast thinking', the enactment of "moves" without engaging in conscious thoughts. The rationale behind this approach could be found in Lemov et al. (2012)'s work underpinned by the principle of "letting the mind follow the body" (p. 33), meaning that you first learn a skill to the level of automaticity and the mind will catch up after. On the other hand, the 'slow thinking' approach focuses on making instructional decision-making explicit, unpacking the pedagogical reasoning, highlighting the instructional purposes and considering multiple instructional decisions that lead to the pedagogical act in a shared instructional context, such as Sherin and van Es' video club model (Gamoran Sherin & van Es, 2009; Kavanagh et al., 2020; Luna & Sherin, 2017).

There are merits and flaws in both approaches. On the one hand, the first approach foregrounds fluency and 'muscle memories' at the expense of reducing teaching to a mechanical work of applying techniques and leaving implicit thinking and tacit knowledge unexamined (Bondie et al., 2019). The problem is that once automaticity and habits consolidate, it is difficult to have conscious access to the thinking process and to change one's habits (Bereiter & Scardamalia, 1993). On the other hand, the second approach makes pedagogical reasoning visible and explicit without providing opportunities for teachers to practise the skills and develop fluency. Alvermann and Hayes (1989) found that reflection alone is insufficient to change teachers' discourse patterns. Successful PD programmes often help teachers to develop both procedural and conceptual knowledge of the pedagogy (Reznitskaya & Wilkinson, 2015).

Contingent responsiveness is not mechanically applying strategies and talk moves in an indiscriminate manner. To develop CR, there has to be a balance between repeated practice to develop a procedural routine and the sensitivity to judge, adapt and innovate in new situations through uncovering tacit knowledge (Hatano & Inagaki, 1986). Shifting between the exocentric and egocentric frame of reference (Dede, 2009), the PD design in this study attempts to reconcile these two approaches, evoking 'fast thinking' by putting participants in the 'hot seat' in the simulation to practise techniques (e.g., talk moves), and 'slow thinking' through subsequent reflection and close emanation of details in the classroom.

2) Situate learning at the edge of learners' competency

When learners are under-challenged, they feel bored; whereas, when over-challenged, they tend to feel deflated and give up (Gee, 2003). The sweet spot is at the outer and growing edge of learners' competence, which is challenging yet do-able (diSessa, 2000). Bereiter and Scardamalia (1993) showed that what distinguishes experts and non-experts over time is the reinvestment of mental resources for progressive problem-solving. The progress and cognitive load of teachers will be monitored closely when creating the simulations to make sure they are just challenging enough for teachers to engage in progressive problem-solving.

3) Leverage interleaved practice to develop teachers' sensitivity in various situations

There exists a tension between decomposition and re-composition of teaching practice (Kavanagh et al., 2020). Decomposing the complexity of teaching allows teachers to focus on the targeted skill, to learn to walk before running (Grossman, Hammerness, et al., 2009). On the other hand, real-life teaching demands that teachers simultaneously manage various dimensions of teaching, and thus it is also important to give teachers opportunities to integrate parsed skills into authentic and complex practice. Otherwise, teachers might focus on specific techniques and lose vision in a broad context. For instance, research consistently finds that teachers tend to focus on the strategies without necessarily advancing student thinking (O'Connor & Michaels, 2019). Therefore, teachers need to develop both fluency with techniques and the sensitivity to recognise the occasions to apply them.

Interleaved practices foster learning of more nuances of concepts, reinforcing memory, enhancing retrieval and increasing the chance of transfer, i.e., applying the concept outside of the context of the learning (Brown et al., 2014). Brown et al. (2014) illustrated the effectiveness of interleaved practice (i.e., mixed-up practice consisting of different tasks) compared to blocked practice (also known as massed practice, i.e., repeated practice focusing on one targeted skill) with two groups of baseball players each training with a different regimen. While the interleaving and spacing of different pitches made learning feel more difficult, the second group performed better compared to the first group who used blocked practice. According to Brown et al. (2014), blocked practice is heavily attached to the learning context, which makes it difficult for learners to transfer the skill to a different context because they have not necessarily developed the sensitivity to recognise the occasion to apply a skill. Contingent responsiveness is situationally dependent, requiring teachers to be sensitive to the occasion. Therefore, the design of this PD programme used interleaved practice, mixing up various types of discussions at different stages of a scientific inquiry instead of having teachers practise CR in only one context.

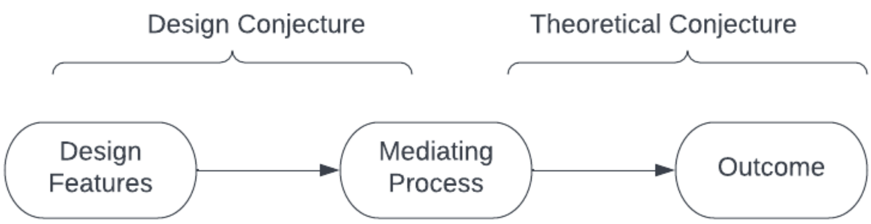
The four high-level conjectures (i.e., design principles) served as guidance for the design of the workshops and simulation sessions. The next section focuses on identifying design and theoretical conjectures from the literature.

4.3 Theoretical conjectures for CR

To uncover the mechanism that led to the change in teachers' practice and understand how teachers develop CR (RQ2), this study used Sandoval's (2014) conjecture maps as a systematic way to map out the path from design features to intervention outcomes.

The *embodied design features* were hypothesised to produce the mediating process, which forms the *design conjectur*e. *The mediating processes* were hypothesised to lead to the desired *outcomes*, forming a *theoretical conjecture* (see Figure 4.1). According to Sandoval (2014), design features do not lead directly to outcomes. He used an example of a plane to illustrate this—the shape of the wings (design features) allows the generation of sufficient lift (a mediating process) for the aeroplane to fly (outcome). A mediating process can be seen as the function of a design that underpins the outcome, which can be produced by various configurations of design features. Using Sandoval's metaphor of a plane, for a plane to fly (as an outcome), it requires a lift (mediating process), though there could be a variety of designs (e.g., a seaplane, passenger plane, helicopter, supersonic plane etc.). Therefore, a conjecture map should not be read as a set of factors leading to an effect, but as a specification of process relations, as a pattern of changes (Sandoval, 2014).

Figure 4.1 Relationship between design features, mediating process, and outcome



Little is known about how teachers develop CR and how to prepare teachers for it (Kavanagh, Metz, et al., 2020). Therefore, I drew inspiration from teacher noticing literature in addition to literature on PD for dialogic teaching to inform the design and theoretical conjectures. Researchers have used the construct of 'teacher noticing' to depict the image of teacher-in-action and to characterise what teachers pay attention to and how they interpret what they see in a multidimensional classroom full of "blooming, buzzing confusion of sensory data" (Sherin, 2011, p. 4), which is the space where CR is situated.

Drawing on the teacher noticing and dialogic teaching literature, I proposed the following three theoretical conjectures:

1) Teachers' flexible attention could lead to CR.
2) Adopting dialogic framings could lead to CR.
3) Developing fluency with a repertoire of techniques could lead to CR.

In the following section, I explain in detail how each mediating process came to be and highlight their conceptual distinctions from the teacher noticing literature.

4.3.1 Deploying flexible attention

To contingently respond to classroom situations and student ideas, teachers need to first attend to them. From a cognitive science perspective, attention is the "voluntary actions that are used to control perception" (Glass, 2016, p. 69). Attention is active and selective in nature (Erickson, 2010; Glass, 2016). Once the target is specified, the frontal cortex selects the target by actively inhibiting other perceptual input that is not the target (Glass, 2016).[6] Mack and Rock (1998) showed that attention is needed for conscious perception from the phenomenon of 'inattentional blindness', i.e., we do not perceive objects that we do not pay attention to. The most well-known example of inattentional blindness is the 'invisible gorilla test'[7], showing that observers often fail to notice unexpected objects when they are cognitively busy engaging in another task (Simons & Chabris, 1999). In other words, we often fail to notice things we do not expect and tend to notice those we expect to see. The classroom is a busy environment full of stimuli, and how teachers deploy their attention will determine what they notice.

So far, the majority of literature on teacher noticing focuses on attending to student thinking and students' disciplinary ideas (Santagata et al., 2021). A recent systematic review found that the large majority of studies on the development of teacher noticing focused on student thinking (83%, n = 29)(Santagata et al., 2021). Student thinking is often deemed as the highest form of noticing. However, the sole focus on students' disciplinary ideas and thinking is problematic in a real classroom environment. Unequal distribution of status and power is not only present in our society, but also carries on in the classroom (E. M. Baldinger, 2017; Kalinec-Craig, 2017). Academic learning is interwoven within a social context. O'Connor and Michaels (1996) cautioned that ideas are often subordinate to social processes, meaning that learning is filtered through complex social interactions. Classrooms have become increasingly diverse with students from different cultures, socioeconomic backgrounds, sex, beliefs, and proficiency in the language of instruction. It is pivotal to take into account these complex social relationships, status hierarchies and implicit power dynamics in the classroom that parallel the inequality found in a stratified society. Research consistently demonstrates unequal participation in classroom dialogue (e.g., Bianchini, 1997; Clarke et al., 2016; Howe & Abedin, 2013; Sedova & Navratilova, 2020)

The forms of talk advocated by dialogic teaching are not always readily available to all members of the classroom and ground rules/discourse norms are not always respected (Michaels et al., 2008). O'Connor and Michaels (1996) exemplified how social relationships could work against group sensemaking—some students do not legitimise the voices of all members of the classroom and

[6] Target selection is not entirely voluntary determined by top-down control. Emotional arousal may play a role, i.e., we cannot ignore something that is emotionally powerful or threatening (Glass, 2016). For example, a sudden loud noise in the classroom will capture the attention as it signals potential threat

[7] In the experiment, the participants watched a video of people (a team wearing black and a team wearing white) tossing a basketball, and their task was to count the number of passes of people wearing white. During the video, a person dressed as a gorilla walked across the scene and beat his chest. Approximately half of the participants did not notice this ongoing and highly salient event when they were engaged in another task of counting the number of passes.

tend to dismiss them based on who the speaker is rather than the merit of the talk. Therefore, teachers' attention should not only be on student thinking; instead, teachers should be prepared to attend to the multifaceted classroom, a view that is shared by Kaiser et al., (2015) and Yang et al., (2020) to include both general pedagogy-related noticing and content-related noticing in their conceptual framework of noticing. In recent years, scholars started to extend their research on teacher noticing beyond student thinking; van Es et al (2017) argued to include 'notice for equity' in addition to notice for students. Louie (2018) illustrated a case of a high school teacher who learned to notice the mathematical strengths of students from a marginalised group. She maintains that teachers' noticing should not only include cognitive processes like attending to, interpreting, and deciding how to respond to students' thinking, but to also manage dominant ideologies that position students, especially students from non-dominant communities (Louie, 2018).

What are the implications for teachers in practice to attend to the multifaceted classroom?
Human brains have limited processing power, and attention is a limited resource (Kahneman, 1973). In addition, the human information-processing system can perform only one ad hoc voluntary response at a time; as a result, divided attention inevitably results in missed targets and lower responses (Glass, 2016). In other words, trying to pay attention to multiple things simultaneously will result in not being able to process anything adequately. Scheiner (2021) argued to shift away from the metaphor of teachers being the 'information processor', by just passively processing the stimuli. He drew on Gibson's (2014) ecological approach to perception, highlighting the role of the perceiver in exploring and interacting with the environment, changing the metaphor of teacher as 'information processor' to "information gatherer". This view takes an agentive view of teachers as perceivers who have the agency to shape what they pay attention to.

Building on the metaphor of teachers as information-gatherers and explorers, I used Eriksen and James's (1986) 'zoom lens model' in conceptualising how teachers can actively and effectively deploy their attention in a multifaceted classroom. This model describes human attention as a zoom lens that is capable of zooming in and out. In other words, the focus of attention can change in size, between sharply focusing on a narrow area and being widely cast over a larger field (Cave & Bichot, 1999; Müller et al., 2003; Schad & Engbert, 2012). In a busy classroom environment, teachers can intentionally shift their attention between a particular event to scanning the whole classroom. For example, during a discussion, teachers can zoom into one student's idea and zoom out to the broader picture of the discussion, and to include the whole class. Using an analogy of a road trip, drivers pay attention to each turn while having the general direction of the trip in mind.

Zooming-in-and-out allows teachers to focus on a particular event and oversee the entire discussion/classroom to contingently respond to students and make in-time adjustments.

In summary, shifting away from the sole focus on student thinking prevalent in the teacher noticing literature, 'attending' in CR implies teachers' agency to direct their attention flexibly, zooming in and out among different facets of a classroom.

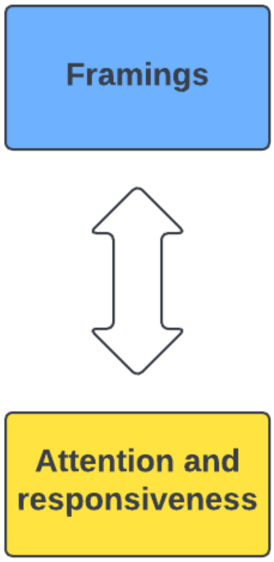
4.3.2 Adopting dialogic framing

Researchers shed light on the irregularity of novice teachers' responsiveness using the notion of 'framing' from socio-linguistics and anthropology (e.g., Levin et al., 2009; Richards et al., 2020; Russ & Luna, 2013). To put it simply, framing is a person's sense of "what is going on in interaction", or "sense of what activity is being engaged in" (Tannen, 1993, pp. 59–60).

Research has shown that teachers' response pattern is partly driven by their framing (Levin et al., 2009; Richards et al., 2020; Russ & Luna, 2013). For instance, there exists an irregularity of the same individual teacher's response to students, which varies from class to class, discussion to discussion, and sometimes even minute to minute (Richards et al., 2020). This finding challenged researchers' belief about a lack of responsiveness being simply a lack of skills because a teacher cannot have the skill and lose it within minutes.

The notion of framing has proven to be useful in understanding how individuals behave differently in situations. Research showed that a teacher's framing of a learning activity drives what teachers pay attention to, how they make sense of the situation, and how they respond to it, illustrated in
Figure 4.2 (Levin et al., 2009; Russ & Luna, 2013). Russ and Luna (2013) found that the same teacher was very responsive to student ideas during a class discussion but was closed to student ideas during lab activities. This variability is driven by the teacher's localised framing that the class discussion is a substantial chance for knowledge building, whereas lab is procedural and follows pre-determined steps. Russ and Luna (2013) argued that framing is self-perpetuating in nature such that the teacher's original framing drives what she notices, and in turn reinforces the framing. In this case, the teacher did not look for opportunities for student sense-making nor engaged with student talk during the lab activity because of her framing that lab is non-substantive and procedure-orientated. As a result, students did not engage in productive talk during lab activities, which in turn reinforced her initial framing.

Figure 4.2 The reciprocal relationship between framing and attention and responsiveness.



As observed in the classroom discussions that teachers shared before the PD, most of the discussions were framed as interactive lectures, which is characterised by IRE/IRF discourse patterns. Therefore, this PD was designed to expose teachers to a variety of dialogic framings of science discussions. The mixed-reality simulations were designed to be task-based and provided the framing of the discussion for teachers. As a result, teachers led a discussion with different framing than that of their pre-PD discussions.

Following high-level conjecture 3 (learning at the edge of competency) and high-level conjecture 4 (interleave practice), the PD exposed teachers to three framings of science discussions that are commonly used in science teaching with increasing complexity: 1) elicitation discussion, 2) consolidation discussion, 3) explanation discussions that are representative of the kinds of intellectual work in a science class (Inquiry Project/Talk Science, 2012)(See Table 4.1).

Table 4.1 Three types of science discussions in this study

Dialogic science discussion framing	When to use	Purpose
Elicitation Discussion	Prior to an investigation; beginning of a unit	• Uncover student' prior knowledge and experience • Increase students' awareness of their own relevant ideas and experiences • Expand and broaden ideas by listening to each other.
Consolidation Discussion	End of an investigation/activity	• Connect inquiry with big scientific ideas • Combine learning from the inquiry with other learning resources
Explanation Discussion	Building on data analysis	• Help students use evidence to support claims • Explain reasons to justify a claim • Describe a scientific principle or reasoning that explains the findings

Aapted from Inquiry Project/Talk Science (2012).

In alignment with high-level conjecture 3, the complexity of the discussion increases as teachers progress in a simulation. The main goal of elicitation discussion is to uncover student ideas. Consolidation involves a balance between students' experience and observation vs. scientific concepts. This requires teachers to orchestrate student ideas into a coherent line of inquiry and towards targeted goals. Lastly, the explanation discussion requires teachers to engage students in authentic science practice by using evidence and reasoning to support their claims, to facilitate students to consider the merits and weaknesses of each other's explanations, and to help students move their thinking forward.

4.3.3 Developing fluency with a repertoire of talk moves

Many PD programmes have sought to equip teachers with a repertoire of discursive moves to enhance their discourse practices (Chen et al., 2020a; Doubler & Paget, 2016; McKeown & Beck, 2004; Michaels & O'Connor, 2015; Windschitl et al., 2018). Families of conversational moves intended to accomplish academic goals are known as talk moves (Michaels & O'Connor, 2015). For example, the 'say more' family of talk moves encourages students to expand and elaborate on their own or others' ideas and contributions, such as "Can you say more about that?", "What do you mean by that?", "Can you give an example?" (Michaels & O'Connor, 2012). Instead of presenting talk moves as isolated moves, Michaels and O'Connor (2015) conceptualised them as tools and categorised them into four foundational goals:

1) help individual students share, expand, and clarify their own thinking;

2) help students listen carefully to each other;

3) help students deepen their reasoning;

4) help students think with others.

These four foundational goals focus on responding to each individual's utterance. During PD, these four goals are often presented as challenges that teachers may encounter when leading discussions. For example, what can teachers do when they did not understand what students said and do not want to embarrass the students? The "say more" talk moves can be helpful in this situation to ask students to elaborate on their thinking. Many research and PD programmes have taken place to support teachers to adopt talk moves in their instruction. Research often reports the increased use of talk moves after PD programmes (Chen et al., 2020; Doubler & Paget, 2016; Michaels & O'Connor, 2015).

Having a repertoire of techniques and strategies is an important aspect of dialogic teaching (Alexander, 2020). According to Mason (2002), to act freshly in the moment not only requires sensitivity to notice the occasion, but also having alternative actions that are ready to be deployed. Therefore, this PD supported teachers with developing fluency with talk moves by practising them in the simulation.

4.4 Initial conjecture map

According to Sandoval (2014, p. 24), a **design conjecture** can be formulated as – "if learners engage in design feature x, then mediating process y will emerge." A **theoretical conjecture** can be formulated as – "if this mediating process y occurs, it will lead to outcome z."

Thus, the initial design conjectures were:

1) Practising techniques during mixed-reality simulations will support teachers to develop fluency with talk moves.
2) Teachers' collaborative inquiry with mini-lectures during the workshop in addition to enactment in the mixed-reality simulation will support teachers to adopt dialogic framings of discussion.

3) The multifaceted elements embedded in the simulated classroom will support teachers to deploy flexible attention to notice multiple facets of the classroom (e.g., student science ideas, lived experience, class equity).

The initial theoretical conjectures were:

If teachers can 1) adopt dialogic frames of discussions, 2) have fluency with a repertoire of techniques, and 3) deploy attention across the multifaceted classroom, then teachers will be able to contingently respond to the multifaceted classroom and students' talk in the moment during dialogic teaching.

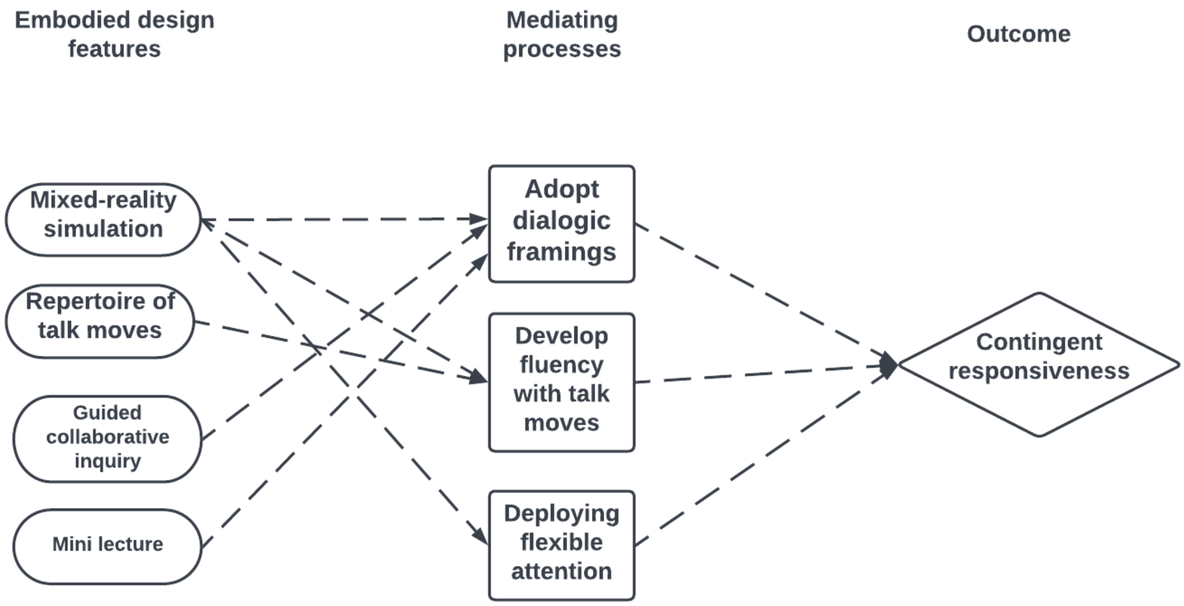
Table 4.2 illustrates design features which embody the high-level conjectures.

Table 4.2 High-level conjectures and the embodied design features

High-level conjectures	Embodied design features
High-level conjecture 1: Inquire with teachers	Collaborative inquiry Mini lectures A repertoire of talk moves
High-level conjecture 2: Combine fast and slow thinking	Mixed-reality simulation (MRS) Post-simulation reflection
High-level conjecture 3: Learn at the edge of the competency	Increasing complexity of MRS scenarios over time
High-level conjecture 4: Interleaved practice	Varied MRS scenarios and types of discussions

Figure 4.3 illustrates the initial conjecture map at Phase 1, depicting the design and theoretical conjectures. The dotted lines represent the tentative nature of the conjectures. The conjecture map was refined after each iteration, which improved the design and learning theory over time.

Figure 4.3 Initial Conjecture Map



4.5 Reflection as a researcher

Pakistan was colonised by British Empire in its history. As a researcher from a UK institution, it is important for me to recognise and acknowledge the history of the hegemonic relation of power (Escobar, 1995). In addition to politics and economy, postcolonial scholars emphasised that a large part of colonisation is cultural dominance and an active erasure of local and indigenous knowledge. To avoid creating a dichotomy between European and non-European knowledge, Khoja-Moolji (2017) drew on Akera's (2007)'s metaphor of ecology to conceptualise the interconnected nature of the forms of knowledge that emerge across different geographical contexts, just like a natural ecology system. Furthermore, Khoja-Moolji (2017, p. 156) suggested that the work of decolonisation entails "looking inward" to reclaim knowledge types that have been seen as irrelevant and position "teachers as knowledge producers."

Gröschner et al. (2014) emphasised the importance of the facilitator's mindfulness, i.e.,
being attentive to the process of teacher learning and each participant. For instance, mindful communication without judgement promotes a trusting atmosphere of learning and exchange. As mentioned in Section 4.1, I noticed that some teachers were nervous about my reaction and evaluation of their teaching. Therefore, I mindfully communicated with teachers about my position as a researcher, who is a co-constructor of learning with them rather than an evaluator. I also did not comment on teachers' classroom discussions or provide any direct feedback at the design stage

of the PD. I framed the retrospective interview as a learning opportunity for me to get to know the teachers, their students, their teaching practice, as well as their classroom context. My mindful and dialogic approach resonated with the teachers, who often voluntarily commented on feeling supported and comfortable with me in the anonymous feedback forms and post-PD reflection.

Extending Gröschner et al (2014)'s notion of mindfulness during PD, I sought to be mindful of my own learning trajectory, emotional state, reactions, as well as dispositions, educational background, and cultural identity as Chinese. I saw the process of creating a PD programme as creating a dialogic space for different voices to merge, clash, and resonate to generated new and augmented perspectives . The fundamental value of the PD is to position teachers as knowledge producers and experts in their own practice. I kept a research journal, continuously examined, and reflected on my role as a researcher from a different cultural background. I reflected to ensure my role did not establish knowledge hierarchy or unjust power dynamics. In addition to personal reflection, I was in ongoing reflection and dialogue with my peers in the faculty who have experience in working and researching in LMICs to shed light on my blind spots.

4.6 Summary of the chapter

Chapter 4 described phase 1 of the DBR, during which I studied the context of the design and consulted the literature on teacher professional development and cognitive science. Four high-level conjectures emerged during the process:

1) Inquire with teachers rather than prescribing solutions
2) Combine fast and slow thinking
3) Learning at the edge of the competency
4) Interleaved practice

Design and theoretical conjectures emerged from teacher noticing and dialogic teaching, illustrated in the initial conjecture map (Figure 4.3). These conjectures were refined across four iterations described in Chapter 5.

Chapter 5 Phase 2: Co-design and four iterations

In this chapter, I discuss in detail the co-design process with practitioners, implementation of workshops and simulation sessions, teacher feedback, my reflection after the implementation, and refinement of the design across four iterations. I start by presenting the co-design process with the teacher coordinators at the school. I then discuss in detail the design decisions for the simulation sessions, including the structure of the session and the design of avatars. Each iteration of the DBR is presented in detail including the design framework of the workshop, instructional activities, design of the simulations, and a sample of the simulation script. After each implementation, I put teachers' feedback and the literature into dialogue to further refine the design in the form of conjecture maps. The iterative processes presented in this chapter illustrate the dialogic relationships between theory and practice, design and implementation, and researchers and practitioners.

5.1 Overview of the iterations

The PD programme had two components:

1) **Collaborative workshops**: teachers engaged in collaborative and guided inquiry, collective reflections to develop conceptual understanding of dialogic science teaching and various talk moves.

2) **Simulation sessions**: teachers put into action their learning from the workshops by orchestrating a science discussion in a virtual classroom with avatar students, just as a pilot learns to fly a plane in a simulator. For example, teachers learned about how to elicit student ideas in the workshop, after which teachers practised leading an elicitation discussion through an authentic task in the simulator.

Therefore, there were two levels of design involved: instructional design for the workshop and simulation scenario design. I co-designed the workshops with the teacher coordinators (see Section 5.2). The design of the scenario involves scripting the situation that the teachers encounter in the simulation, including the classroom context, student characters, student ideas, student lived experience, and equity issues. The simulation scenarios were developed in collaboration with the simulation specialist (see section 5.4. The co-design and implementation of the four workshops and simulations span across eight months, from April to November 2021. (This does not include preparation work to set up the simulation and understand the design context, which took 4 months). The simulation sessions usually took place the same week or the week after the workshop.

Table 5.1 presents the timetable of the four DBR iterations.

Table 5.1 Timetable of 4 DBR iterations

	PD topic	Co-design meetings	Workshop	Simulation
Iteration 1	Ground rules and simulation orientation	April 21st	May 6th, 2021	May 18th-21st ,2021
Iteration 2	Features of dialogic discussion & elicitation discussion	June 10th	June 16th, 2021	June 23rd- July 5th , 2021
Iteration 3	Discussion as sense-making & consolidation discussion	September 29	October 14th, 2021	October 23rd -28th , 2021
Iteration 4	Moving student ideas forward & explanation discussion	November 15	November 30th, 2021	December 4th -11th , 2021

5.2 Co-design workshops with teacher coordinators

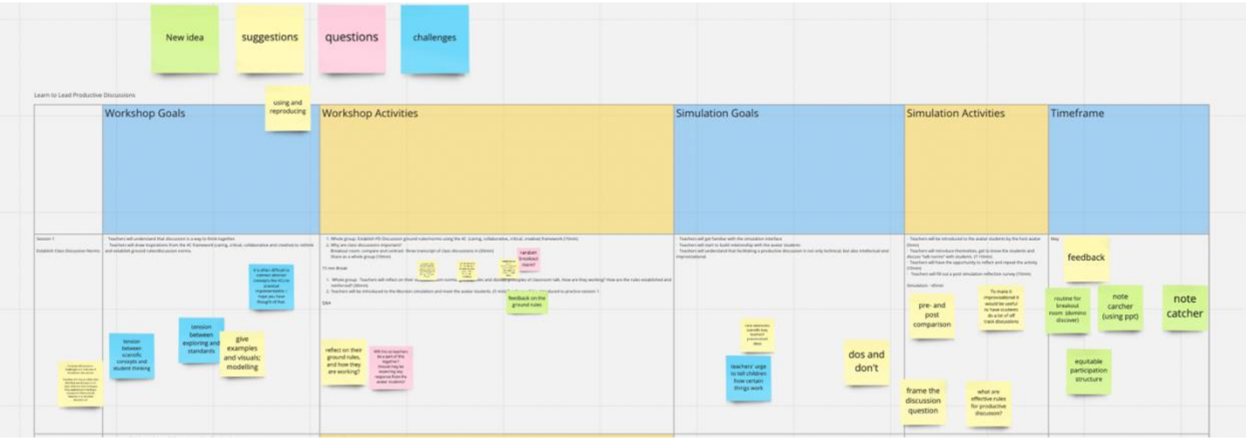
Each workshop was co-designed with school coordinators, who were in charge of their grade level. Teacher coordinators are very busy overlooking the teaching and learning of the entire grade level, and it was important to make sure the co-design time we spent together was efficient. For this reason, I drafted the blueprint of the workshop in advance on Miro Board (a collaborative virtual whiteboard). During the co-design session, coordinators suggested new ideas, provided suggestions, asked questions, or explained challenges in their context by manipulating the colour coded sticky notes (See Figure 5.1). For example, in the first co-design session, teacher coordinators brought up the challenges of connecting abstract pedagogical concepts to practical implementation, the difficulty in balancing exploring student ideas with curriculum standards, and the importance of giving examples, providing visuals and modelling during the workshop. They also raised logistic and technical issues such as how to assign people to breakout rooms and how the avatar students respond to the teachers. They also provided knowledge about science education in their context.

One teacher coordinator wrote:

> For instance, they [students] often view science as a collection of dusty, old facts rather than a dynamic, evolving state of how we best understand the world. School practices that don't provide opportunities to learn how scientists come to know and find out can contribute to these misconceptions.

Teacher coordinators would then choose a few sticky notes that they thought were most important to propose to the whole group. We would then build on each other's ideas, ask clarifying questions, or offer alternative suggestions. After the session, I incorporated the suggestions and feedback into the design. The teacher coordinators were not directly involved in scripting the simulation scenarios. However, they were responsible for verifying the portrayal of the character and narrative of the scenario to ensure that it was contextually and culturally appropriate before delivering it to teachers.

Figure 5.1 Co-design with teacher coordinators on Miro board



5.3 Design of avatars

Since the research took place in Pakistan, initially, I wanted the avatars to reflect the school's demographic makeup, student behaviours, and characteristics. Due to the technical limitations, it was unfortunately not possible to design a new avatar that reflects the physical appearance of the students and the school environment. It would have taken much time and financial investment to develop new avatars, which was beyond the budget and time frame of the study. As a result, this study used the default five avatar students in the simulation environment, namely Savannah, Dev, Ava, Jasmine, and Ethan (See Figure 5.2). The five avatars appear to come from a diversity of backgrounds, each with unique characters (See Appendix 7 for the personality and characteristics of each avatar).

Drawing on the notion of 'case pupils' in lesson studies (Dudley, 2013), the characters of each avatar student typify a learner group whom it is important to understand in dialogic teaching. For example, in dialogic discussions, some students feel more comfortable expressing their ideas than others, and it is easy for a few students to dominate the discussion (Michaels et al., 2008). The avatar, Ethan, represents this kind of learner who is very expressive and energetic and often dominates the discussion. It is important to highlight that the simulations do not seek to stereotype individual students, but rather to exemplify typical behaviours observed within the classroom of the local context.

Figure 5.2 Five avatar students: Savannah, Dev, Ava, Jasmine, and Ethan (from left to right)

The simulation specialist (who portrayed all five avatars behind the scenes) is a full-time teacher from the United States. Therefore, she was able to portray students in the US cultural context realistically, but I was not sure if the portrayal of the characters would be appropriate in the context of the school and Pakistan. To address this limitation in advance, I met with the school leadership team to show a demo of the simulation environment and the portrayal of avatar students to make sure it was culturally appropriate and sensitive, avoiding stereotyping and bias. The leadership team reported that they could relate to the avatar students on a personal level. They were able to connect the personalities and behaviours of the avatar students to their own students at the school. They did not find that the appearances of avatar students hindered their ability to connect to them, and they were unconcerned about the American accents in their speech. To ensure that the simulation was culturally appropriate and sensitive, teacher participants were also asked for their feedback after each simulation session. It is important to highlight that the student demographics of the school are not necessarily representative of other school contexts in Pakistan. While the teachers reported that they could very well relate to the avatar students in this case, this cannot be generalised to another school context in Pakistan. Therefore, it is critical to include local practitioners in the design process to tailor the simulated classroom to their context.

5.4 Designing scenarios with a simulation specialist

The simulation class was set to be a Grade 5 class to accommodate the range of grades that teacher participants teach (from early years to O level). Grade 5 was selected so all teachers can relate to certain aspects of the classroom. For example, the early years teachers would not find the students too mature that they could not connect with their own teaching. Each simulation scenario was written in collaboration a simulation specialist. Since the simulation specialist is also a full-time working schoolteacher and part-time actress, it is important to ensure the co-working time is efficient.

My role in the collaboration was to suggest the learning goals of the simulation, the narrative of the scenario, and write potential speech turns for the avatars, which were then adapted, refined, and improvised by the simulation specialist. The simulation specialist provided feedback on the scenario and suggested the delivery and portrayal of the characters

In terms of participant structure, teachers participated in the simulation session in pairs for three reasons. First of all, co-teaching is part of the practice at the school, so it adheres with their day-to-day practice. Secondly, teaching in pairs makes teachers feel more comfortable about interacting with something completely new (avatar students). Thirdly, teaching in pairs gives teachers a window to observe other teachers' practice and creates opportunities for collective reflection and feedback. The entire simulation session (with two rounds) lasted 40 to 60 minutes (the duration increased as teachers progressed). The design trade-off was that teachers did not have the opportunity to repeat the simulation session to incorporate their feedback and reflection. We decided it was more important for first-time teachers to feel emotionally safe with the new technology than to give them the opportunity to repeat the simulation. These design assumptions were later verified by teachers' feedback.

The structure of the simulation session drew inspiration from Wegerif et al. (2003)'s Initiation, *Discussion*, Response, Feedback (I*D*RF) exchange pattern (also see Wegerif, 1996, 2004). Unlike the IRF pattern (Cazden, 2001), computer software is used to stimulate discussion (I), and discussion (D) among the peers is purposefully integrated into the sequence, where students jointly come up with ideas before testing them out in the computer (R) for feedback (F). The integration of discussion into the sequence allowed for the joint construction of meaning and understanding.

Wegerif et al. (2003) applied the I*D*RF on the computer software called 'bubble dialogue', offering a flexible way of externalising dialogue, supporting shared reflection, shared construction, and re-construction. The simulated classroom shared a similar affordance as bubble dialogue to externalise dialogue, rewind dialogue, reflect, and re-enter the dialogic space, which is not possible in a real-life classroom. For example, teachers could test a strategy in the simulation, reflect with their peers, re-enter the same scenario and test out the adjustment. Because the simulated classroom approximates the fast-paced nature of a real classroom, the discussion (D) component is placed at the end of the simulation, following an IRF pattern. In this study, because teachers participated in the simulation in pairs, they could observe each other's teaching and make adjustments when it was their turn. In consultation with the simulation specialist, we decided to also offer teachers opportunities to pause in the middle of the simulation to reflect with their peers following the I*D*RF pattern.

The simulation sessions were structured into the following components:

1) Introduction and recall
2) Preparation
3) First round of simulation
4) Post-simulation reflection
5) Preparation
6) Second round of simulation
7) Post-simulation reflection
8) Feedback form

Each simulation is a mix of standardisation and improvisation, meaning that a number of standardised elements were be delivered to all participants. For example, in the first simulation, Savannah always asked the question "why do we need rules? We are not children" to all teachers. On the basis of the standardisation, the simulation specialist improvised depending on the individual differences of each teacher and how they decided to lead their discussion. The simulation specialist and I always rehearsed the scenario before delivering, during which I played the role of participating teacher and provided feedback to the simulation specialist on the delivery. We also tweaked the scenarios and speech turns after the rehearsal.

Another design decision we made was to keep the classroom management aspect of teaching (e.g., student misbehaviours) at a minimal level in the simulation to have teachers focused on responding to student science ideas, lived experience and classroom equity, allowing teachers to practice in 'calm water'.

5.5 Instructional design framework and PD topics

The instructional design of the PD uses the instructional framework of "Teaching for Understanding" (TfU) (Wiske, 1998). The TfU framework has four elements:

- Generative topics: identify what is worth understanding.
- Understanding goal: clarify what learners need to understand.
- Performance of understanding: foster learning by engaging them in performances of understanding that require learners to apply, extend and synthesise what they have learned.
- Ongoing assessment: monitor and promote learners' progress.

Generative topics answer the question of what is worth teaching and learning and are central to the domain and discipline. According to Wiske (1998), generative topics engage learners in developing a foundation for more sophisticated work in the domain (e.g., central concepts and important modes of inquiry). In addition, given the diverse background and grade levels of teachers, the topics of each PD session must be selected in a way that has generative potential. The generative topics identified were:

1) establish ground rules and simulation orientation
2) features of dialogic discussion and elicitation discussion

3) sense-making and consolidation discussion

4) moving student ideas forward and explanation discussion

5.6 Iteration 1: Ground rules and simulation orientation

5.6.1 Workshop 1 design

Table 5.2 presents the instructional design of the first PD session using the TfU framework. The design features and the corresponding activities of the workshop are shown in Table 5.3.

Table 5.2 Design framework of iteration 1

Generative Topic	Establish ground rules and simulation orientation
Understanding Goals	1) Teachers will understand that discussion is a way to think together. 2) Teachers will draw inspiration from the 4C framework (Phillipson & Wegerif, 2016)(caring, critical, collaborative and creative) to rethink and establish ground rules/discussion norms. 3) Teachers will understand the purpose of the simulation is for them to enact their learning in a safe and low-stakes environment, and accessing the simulation is the same as attending a video conference in zoom. 4) Teachers will understand avatar students can respond to them in real-time and the interactions between them are authentic and similar to a real classroom.
Performance of Understanding	For teachers to get familiar with the simulation environment and feel comfortable teaching the avatar students, and practise using the 4C framework to develop ground rules with their students, teachers were given the following tasks in the simulator in pairs: 1) get to know your class of Grade 5 students in a virtual class (7-10min). 2) Establish discussion ground rules with the students for future class discussions. (7-10min).
Ongoing assessment	Teachers engage in collective reflection of the video recordings of the simulation.

Table 5.3 Design features and activities of workshop 1

Design Features	Activity
Community building[8]	"What is the weather today?" Teachers and the researcher described the external weather (e.g., sunny, cloudy rainy) and their internal weather (e.g., excited, apprehensive, joyful etc.)
Collaborative Inquiry	1) Teachers come up with ground rules for the workshops in the breakout room and share them with the whole group. 2) Jigsaw[9]: Exploring the 4c framework to rethink ground rules Teachers worked in breakout rooms in jigsaw format to read about each dimension of the 4C framework (i.e., caring, critical, collaborative, and creative) and discuss how the framework can inform the ground rules they have in their class.
Mini lecture	1) What are the ground rules? 2) Introduce simulation and task Teachers watched a short video on what the simulation environment looks like. The researcher informed teachers about their upcoming simulation tasks and the learning goals.

5.6.2 Workshop 1 implementation and feedback

The pilot workshop took place on May 6th, 2021, for 1 hour 9 minutes. Thirteen teachers participated in the workshop, and six of them provided anonymous feedback via google forms. All of the questions were free response except question 5. Teachers' responses are summarised below:

1) **What is helping me to learn in this workshop?**

Half of the teachers mentioned collaborative inquiry. One teacher mentioned the mini lecture.

2) **What changes are needed in this workshop to improve learning?**

4 teachers answered this question. Two of them said they did not think there needed to be any change. One asked for more detailed instructions and one asked for a slower pace.

[8] Community-building is essential for teachers and researchers to form a rapport with each other, creating an open and safe PD environment for learning. It is not included in the conjecture map as it does form part of the acquisition of CR.

[9] Jigsaw is a collaborative learning activity, in which each learner focuses on one specific topic and becomes the expert of the topic, and then they come together in groups to share information together.

3) **At what moment during the workshop did you feel most engaged with what was happening?**

Two teachers mentioned mini-lectures, and two teachers mentioned collaborative inquiry. One teacher mentioned the community building activity. One teacher said she felt engaged the whole time.

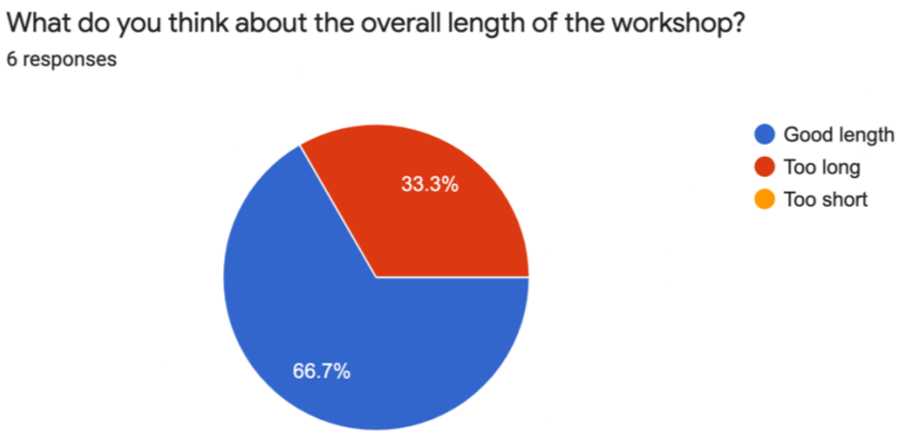
4) **At what moment during the workshop were you most distanced from what was happening?**

Two teachers mentioned at the beginning of the workshop that the instructions for the task were not clear. One teacher mentioned she had difficulty understanding how the simulation would work.

5) **What do you think about the overall length of the workshop?**

As shown in Figure 5.3, Most of the teachers though the length of the workshop was good (66.7%).

Figure 5.3 Teachers' feedback on the length of Workshop 1



6) **Anything else you want to add?**

Four teachers answered this question. Three teachers praised the workshop, and one teacher asked for more guidance on the 4C framework.

Summary of teacher feedback for Workshop 1

In summary, teachers enjoyed learning as a team in breakout rooms and learning about the 4C framework. However, some of them felt they did not have clear instructions for the breakout rooms, and they would appreciate more detailed instructions. Some supplementary reading material would be helpful for teachers who would like to engage in further reading.

According to my field notes, the workshop went generally well. I noted the following self-critique. The community-building activity was conducted as a whole group because I wanted to be present to build connections with teachers (as it was not possible to be present in different breakout rooms simultaneously). As a result, the community-building activity took longer because teachers had to take turns, and there were not many interactions among teachers. In retrospect, I could have created breakout rooms so everyone had more time to speak to each other. Because I already knew all of the teachers from meeting with them through the individual interview, I could visit each breakout room briefly. Having teachers come up with ground rules for the workshop was intended to model negotiating ground rules with students, but I did not explicitly make the connection for teachers, so I was not sure if teachers internalised that ground rules can be negotiated with students to have them take ownership rather than being established for them.

Here were the actions points for refinement:

1. Community-building activity in breakout rooms
2. When modelling is used, help/prompt teachers to make connections with their own teaching
3. Provide written instructions and note catcher for teachers before sending them to breakout rooms, so they have the instructions with them if they need to double-check
4. Continue with small-group collaborative inquiry and mini-lectures
5. Provide supplementary reading materials that teachers can consult

5.6.3 Simulation 1 design

The pilot simulation session was designed for 7-9 minutes, intended as an orientation for teachers to familarise with the simulation environment and feel comfortable with interacting with avatars in addition to giving teachers the opportunity to enact their learning from the workshop i.e., try out setting ground rules with students.

The simulation had two tasks. In the first part of the simulation, the task was to get to know the virtual class of grade 5 students. In the second part of the simulation, the task was to establish discussion norms/ground rules with avatar students for future science class discussions. In each round, one of the teachers acted as the lead teacher and the other served as an assistant teacher/observer. The lead teacher did most of the teaching and interacting with the students, and the assistant/observer carefully observed the teaching moves that the lead teacher made (she was allowed to jump in to support the lead teacher as if she was co-teaching in a classroom). There was a reflection between the first and second simulation for the lead and observing teachers to reflect together and switch roles to prepare for the second round of the simulation. In the two scenarios, we embedded three elements of the multifaceted classroom for teachers to notice and respond to: student science ideas, student lived experience, and classroom equity issues.

Table 5.4 summarises the structure and shows a sample script of the pilot simulation.

Table 5.4 Pilot simulation design

	Activity	Sample Script
Introduction with opportunities for recall	- Recall takeaways from the workshop - Remind teacher goals of the simulation	- I know that you have had a workshop with Lydia. In one or two sentences, can you remind me what you learned in the workshop and what your takeaways were?
Preparation	- 2 minutes to prepare for the simulation	
Simulation Round 1	- Get to know the class - Opportunity to respond to fostering an equitable community	Teachers get to know each avatar student. Each avatar student has a unique personality and hobbies. For example, Savannah is often quiet in class, and she likes reading and fiction. In the scenario, we embedded classroom equity issues for teachers to notice and respond to. Ethan is very energetic and active and often ends up dominating the classroom and not giving other students a chance to speak.
Reflection	- Opportunity for reflection on action immediately after the simulation - Elicit different teachers' perspectives of the same moment	- For our lead teacher, tell me about a moment or a teaching move you felt particularly good about. - Is there a moment from that simulation you would like to have done differently? Tell me about that moment and what you would like to adjust. - Let's have our assistant/observer reflect on that moment. What did you see, or what other ideas or suggestions might you add?
Preparation	2 minutes preparation	
Simulation Round 2	- Establish ground rules in the class	In this scenario, the three standard elements that were implemented across all simulations were: 1. **Why do we need ground rules?** We scripted one student to question the need to have ground rules in the classroom to have teachers communicate the rationale of ground rules (part of their learning in the workshop). 2. **Student lived experience** Have one student speak about the ground rules of a game that they play (Minecraft, football, fortnight, table tennis, among us, Fortnite). Example: In Minecraft, we never dig straight down (or up) because you may run into lava, and you will burn along with your stuff. You need to know these rules to play well! (Give the teacher a moment to respond) 3. **Student science ideas:** Dev says: "use good evidence to back up your argument". Teachers should notice that students are bringing in their science ideas to the discussion and think about whether other students understand what counts as good evidence. This is a moment for teachers to ask students clarifying questions. If the teacher does not clarify what evidence means, other students can act unsure.
Reflection	- Connecting back the theoretical learning in the workshop	- For our lead teacher, how do you feel that you utilised the 4 Cs (creative, collaborative, critical, caring) in this simulation? Can you name a specific moment where you displayed one of the 4 Cs? - For our assistant/observer, how did you see the 4 Cs integrated into the simulation?

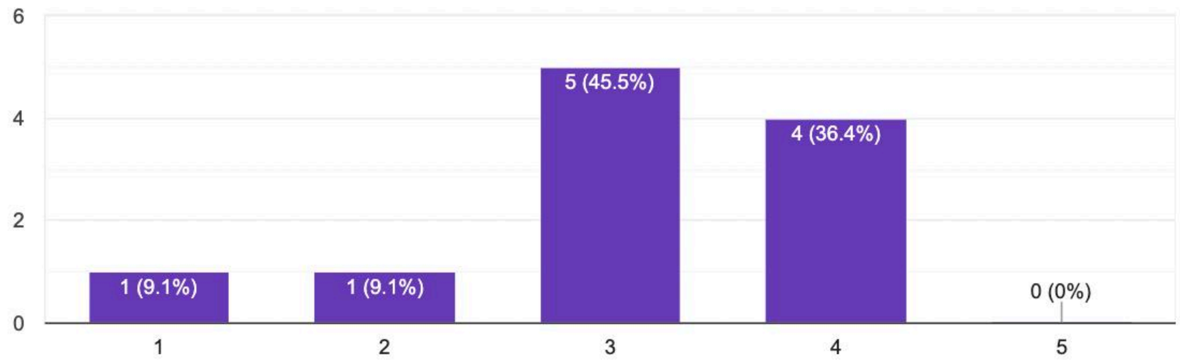
5.6.4 Simulation 1 implementation and feedback

Thirteen teachers participated in the simulation and 11 of them provided anonymous feedback via google forms. I summarised teachers' feedback below.

1) Cognitive load

Cognitive load was used to gauge how challenged teachers felt in the simulation to make sure the simulations were challenging enough for teachers to progress and at the same time not too challenging that they feel deflated (High-level conjecture 3). 4 teachers (36.4%) experienced a high cognitive load in the first simulation, which was not unexpected because this was their very first simulation (See Figure 5.4). Ideally, I would like teachers to feel challenged, but not overly challenged (roughly a score of three). None of the teachers felt overly challenged. One teacher felt under-challenged, which might have to do with the simplicity of the task. Overall, the results showed that keeping the orientation simulation simple is vital because most teachers still experienced a high cognitive load as they engaged in a completely new experience with avatar students.

Figure 5.4 Teachers' self-reported cognitive load during Simulation 1



2) Memorable moment

Memorable moments were used to gauge which design feature stood out to teachers and their general experience in the simulator. Ten out of eleven teachers' responses focused on their interactions with the avatar students. Teachers provided vivid accounts of their interactions with avatars. A thematic emic coding revealed that surprisingly almost half of the teachers (46%)

reported the most memorable moments were feeling a sense of connection with the avatar students (See Figure 5.5).

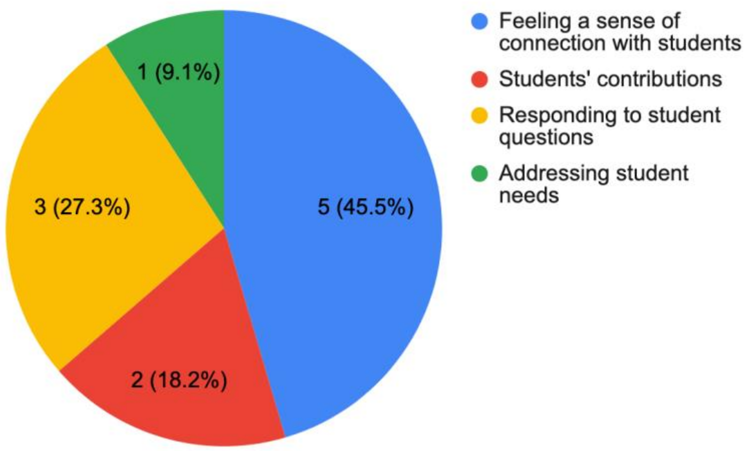
Examples of teachers' responses include:

> The memorable moment was the whole class because I did not feel like a stranger. It felt like I was talking to my own class that I am having for a few months. I hope I responded well, and the children liked me.

> The whole simulation was a great experience. I responded like I do with my students. I responded this way so the students can open up to me more and could be more comfortable with me.

> The moment when Jasmine was telling us that she volunteers at an animal shelter and likes dogs and I told her that Ma'am Amna has a dog as well. It was wonderful to experience to build that connection with her and share her excitement.

Figure 5.5 Teachers' memorable moments in Simulation 1

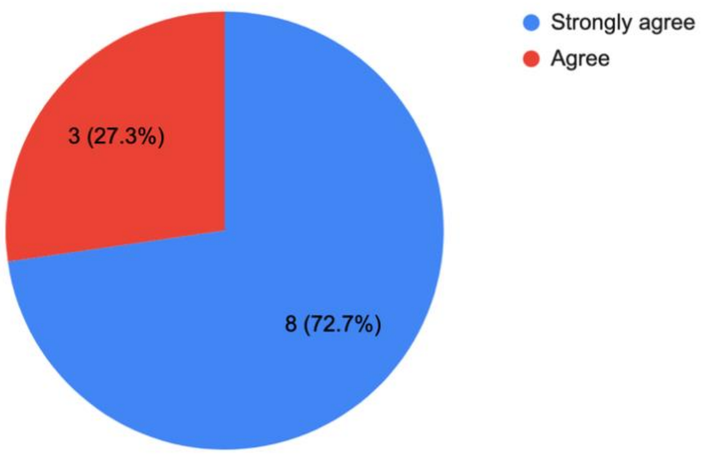


This result addressed one of the earlier concerns on using simulation for dialogic teaching. The foundation of dialogic teaching is genuine relationship among teachers and learners. Simulation might be a promising environment to practise techniques, but it does not allow authentic relationship building. It was surprising that the first thing that teachers did in their very first simulation was to build relationships with the students and feel a sense of connection. This demonstrated that teachers were able to develop a sense of relationship and connection with the avatar students. This result also showed that the suspension of disbelief was present during the simulation, and teachers were able to treat the simulation as an authentic situation to engage with students to practice dialogic teaching.

3) Simulation as a reinforcement for teacher learning

All of the teachers found that the simulation reinforced their learning in the workshop (See Figure 5.6)

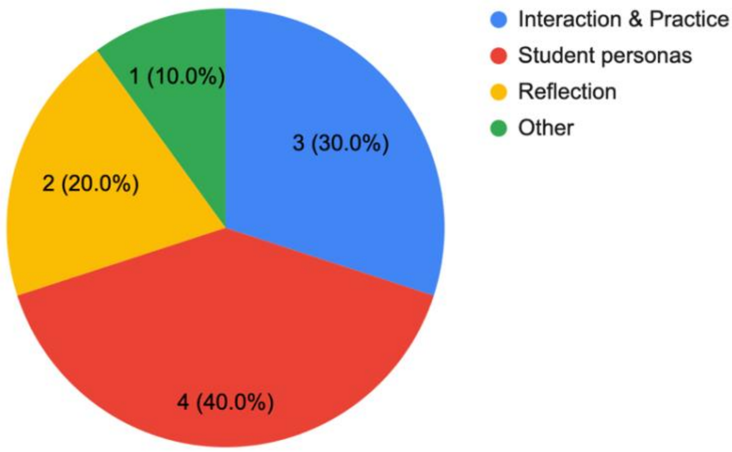
Figure 5.6 Simulation 1 as a reinforcement of the workshop



4) What is helping me to learn in this simulation?

Teachers' responses were coded thematically using emic codes. Figure 5.7 illustrates that 40% of mentions were about student personas, 30% were on interaction and practice, and 20% were on the reflection. These results showed that teachers benefited from putting their theoretical learning into practice in a contextualised scenario and have situated reflection rather than genetic reflection.

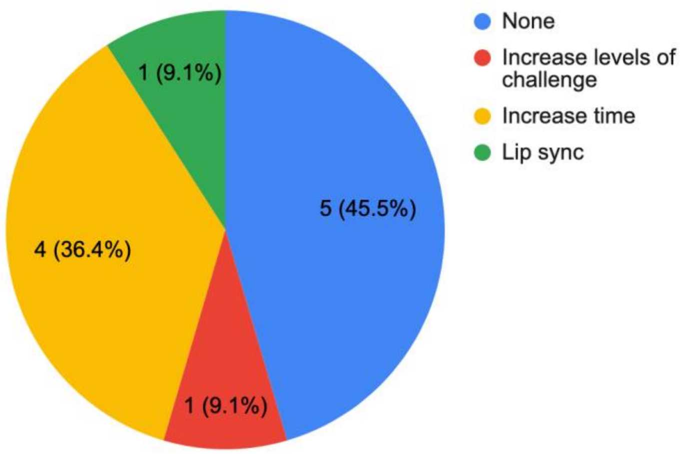
Figure 5.7 Design features that teachers found helpful to their learning in Simulation 1



5) What changes are needed in this simulation to improve learning?

Four teachers (36%) asked for more time in the simulation, and one teacher thought we could add more challenging elements to the scenario (e.g., student misbehaviour) (See Figure 5.8). This result showed that the teachers were ready for a longer and potentially more challenging scenario.

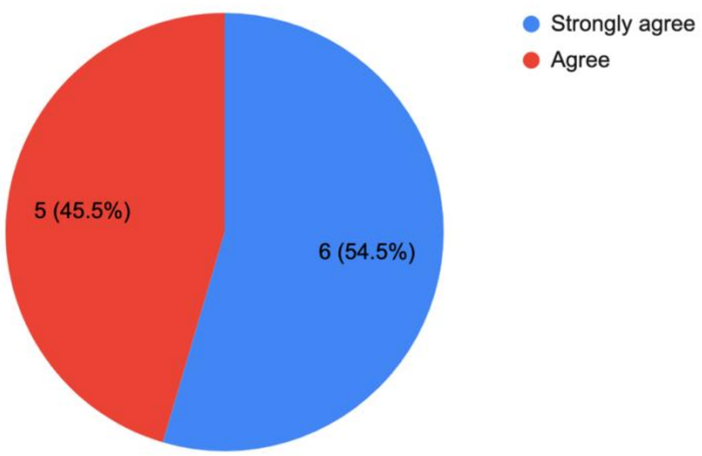
Figure 5.8 Teachers' suggestions for improvement in the Simulation 1



6) Cultural appropriateness of avatar students

All of the teachers either agreed or strongly agreed that the avatar students were portrayed realistically and were culturally appropriate, which resonated with the responses of teacher coordinators during the co-design session (See Figure 5.9). However, we could not assume that this would apply to all simulation sessions as there were always elements of improvisation. Therefore, teachers were asked for their feedback on the avatar students after each simulation session.

Figure 5.9 Cultural appropriateness of the avatar portrayal in Simulation 1



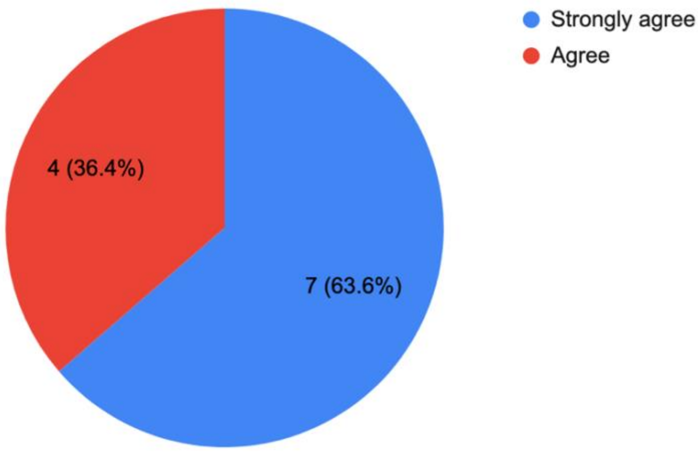
7) What changes in the avatar students would you like to suggest?

Most of the teachers did not suggest changes for avatar students. One teacher asked the avatar students to speak more clearly, and another teacher asked for lip sync. The simulation technology allowed avatars' lips to move when speaking, however, it is not entirely synced with the speaking. This is one of the technical limitations of the simulation at the moment.

8) The workshop prepared me sufficiently for the simulation

Figure 5.10 shows that all of the teachers agreed (36.4%) or strongly agreed (63.6%) that the workshop sufficiently prepared them for the simulation.

Figure 5.10 Adequacy of workshop as preparation for Simulation 1



9) What additional support would you have liked to help you prepare for this simulation experience?

Six teachers answered this question. Two teachers asked for reading materials for the simulation. Four teachers said they did not have any suggestions.

10) Other comments

Two teachers expressed their enjoyment of the simulation learning experience. One teacher expressed her apprehension before attending the simulation, but she found the presence of the researcher made her feel relaxed. One teacher asked about the simulation technology, in particular, whether the facial expression of the avatar students matches the feeling of the children at the moment, or it is just the default mode, which I addressed in the next workshop.

Summary of teacher feedback for Simulation 1

According to my fieldnotes, six pairs of teachers participated in the pilot simulation. Four pairs of teachers approached it as establishing rules for students rather than with students. From a design perspective, I think this might have to do with the lack of explicit connection made between modelling in the workshop and teachers' practice. Another possibility was the wording of the task, which said the task was to "establish discussion norms/ground rules with your students for future science class discussions. The wording of 'establishing' might frame the discussion as teachers presenting rules for students rather than exploring possible ground rules with students. As discussed earlier, teachers' framing influences teachers' noticing as well as discourse patterns.

According to teachers' feedback, I summarised the following points for refinement in the next simulation session.

1) Expand the duration of the next simulation session
2) Provide materials for teachers in advance to consult before the simulation
3) Address the questions about the facial expression of avatar students
4) Help teachers make connections between exemplars and their own teaching
5) Frame the task into a dialogic discussion with a careful selection of wording

5.6.5 Reflection as a design researcher

So far, the PD design has not included a component for self-reflection and feedback beyond the short post-simulation reflection during the simulation session . Feedback is critical for learning, but depending on how it is used, the impact can be positive and even negative (Hattie & Timperley, 2007). According to Mason (2002), to support other people effectively in their professional development is not to offer solutions, not to suggest what they 'should' do—at best one can offer things they could do (p. 145). The reason is that simply offering a solution leads people to feel defensive and inadequate rather than safe and open to considering other possibilities. Adhering to high-level conjecture 1 (inquiring with teachers rather than prescribing solutions), how can I support teachers to generate insightful feedback for themselves and each other rather than me giving direct feedback?

Initially, I made a personal reflection form for teachers with targeted questions, directing teachers' attention to certain moments of the simulation for reflection, which they could complete individually. Before implementing it, I asked teacher coordinators for feedback on this type of reflection, They thought this reflection exercise might not provide sufficient engagement and motivation for teachers. The disadvantage of personal reflection is that it is individual, without voices from the outside and interaction with others. Teacher coordinators' feedback led me to conduct more research to refine the design of the reflection exercise and alternative ways to provide feedback.

Hattie and Timperley (2007, p. 81)'s conceptualisation of feedback is "information provided by an agent (e.g., teacher, peer, book, parent, self, experience) regarding aspects of one's performance or understanding. However, feedback from a teacher, a peer, a book, a parent, self, and experience are very different both practically and conceptually. Using Mason's (2002) distinctions between ‘extra-spection’, ‘intra-spection;, and ‘inter-spection’ (illustrated in Figure 5.11), I distinguish three ways to provide feedback:

1) *Extra-spection* observation, according to Mason (2002), is observing from the outside, which can “alert practitioners… to the absence of sensitivities, to habits which are getting in the way, and to alternative actions (p. 86).” Rather than providing direct feedback to highlight the gap between the current performance and the desired one, Mason (2002) suggested exposing teachers to alternative practices, modelling them, and providing case studies (in forms of videos, audio, or written transcript) in PD settings.

2) *Inter-spection* observation describes interactions between colleagues. Different from extra-spection, inter-spection forms a shared or taken-as-shared world of experience. For example, teachers develop common languages (i.e., labels) for collections of similar incidents and actions.

3) *Intra-spection* observation describes the development of teacher’s inner observer who watches and witnesses actions and informs practice in the moment by bringing to fore alternative possibilities of actions.

Inspired by Mason’s three types of feedback, my role as a researcher and PD designer from an extra-spective perspective is to open a dialogic space for teachers’ collective reflection and widen it by bringing other voices, such as literature and case studies. For example, I could provide teachers with case studies of different discussions (e.g., dialogic/non-dialogic) that they could examine collaboratively and connect to their own practice. Furthermore, I could facilitate inter-spection and provide opportunities for teachers to engage in a collective reflection about their shared experience in the simulation. Lastly, I could strengthen teachers' intra-spection by having them return to the situation and consider alternative possibilities right after they finished the simulation (i.e., post-simulation reflection).

Figure 5.11 Differences between Extra-spection, Inter-spection, and Intra-spection (Mason 2002, p. 85)

Photo removed for copyright reasons. Copyright holder is John Mason.

Knowledge-based reasoning

So far, in the conjecture map, there lacks a mechanism of how teachers interpret and make sense of what is observed/noticed by teachers. How teachers interpret what they notice is defined by van Es and Sherin as (2002, p. 573) as a form of knowledge-based reasoning:

1) Use one's knowledge and experiences to make sense of what is observed
2) Make connections between what is noticed and broader principles of teaching and learning

For example, a teacher could reason about a particular event based on knowledge about the subject, curriculum, and students. (Gamoran Sherin & van Es, 2009).

Knowledge-based reasoning is a kind of 'slow thinking' that teachers need to engage in order to improve and expand their practice. Therefore, the PD needs to carve out a space for knowledge-based reasoning and support teachers with this process. In addition to being a space for 'inter-spection', collective reflection also provides opportunities for teachers to engage in knowledge-based reasoning, to explain their in-the-moment thinking, to be explicit with the reasons of their response, and to examine their tacit knowledge, which can be enriched and challenged by other perspectives. Furthermore, comparing and contrasting cases also provides teachers with opportunities for knowledge-based reasoning as they require teachers to distinguish the discourse pattern and pedagogical reasoning of different types of discussions. Finally, the simulation guide will provide teachers with a repertoire of content knowledge (CK), pedagogical knowledge (PK), and pedagogical content knowledge (PCK) corresponding to the scenarios of the simulation, so they can better prepare for the simulation and reason about their pedagogical decision-making. CK, PK, and PCK are situated within the simulation scenarios and close to practice, allowing teachers to learn by applying them in the simulation.

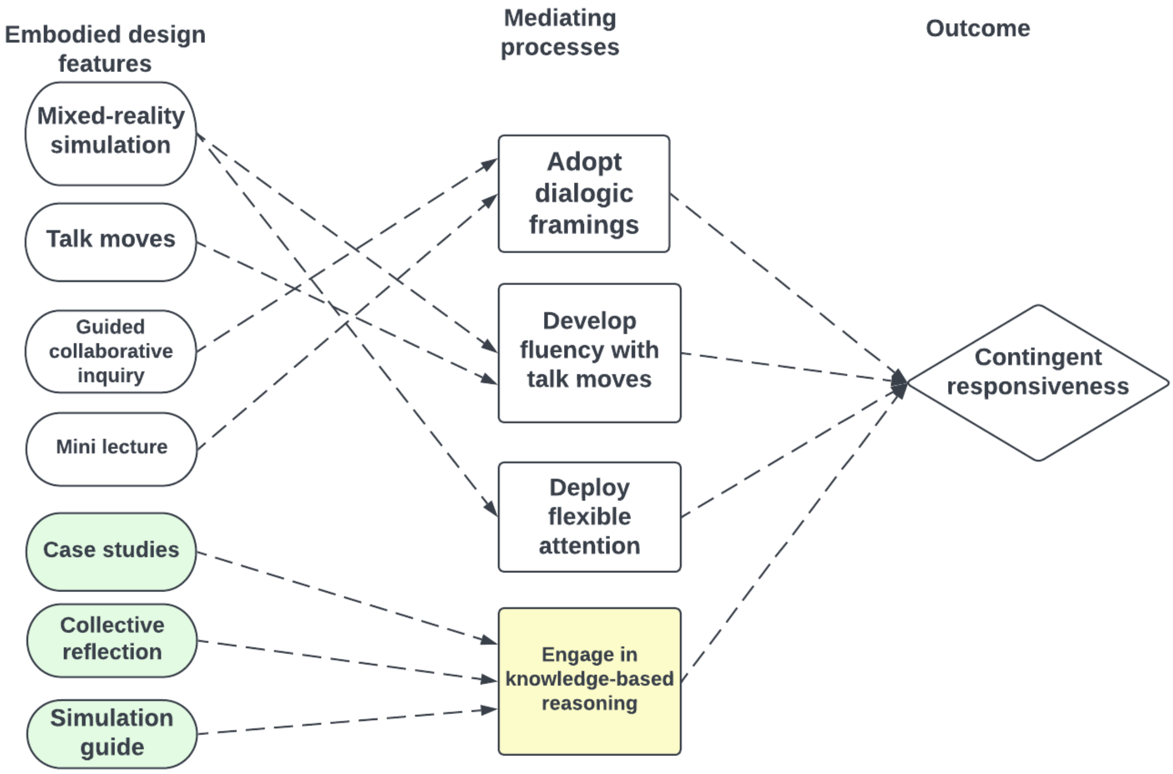
5.6.6 Refined conjecture map

Teachers' feedback, my observation, and my reflection as a researcher and designer allowed me to refine the conjecture map in Figure 5.12 (new features were highlighted in green). The dotted lines represent the tentative nature of the conjectures.

In the next iteration, I decided to:

1) Widen the dialogic space by bringing examples/case studies into the next workshop (scenario-based task).
2) Instead of having each teacher individually reflect on the simulation, build in "inter-spection" time for teachers to collectively observe and reflect (i.e., engage in knowledge-based reasoning in collective reflection) in the next workshop.
3) Build teachers' "intra-spection" in the next simulation to reflect on what they have observed and consider alternative actions (post-simulation reflection).

Figure 5.12 Refined conjecture map after the pilot (Iteration 1)



5.7 Iteration 2: Features of dialogic science discussion & elicitation discussion

5.7.1 Workshop 2 design

The goal of the workshop is for teachers to gain a macro-level overview about productive dialogic science discussions and learn to lead an elicitation discussion while attending to student science ideas, lived experience and classroom equity. Elicitation discussions help to uncover students' prior knowledge and experience, which allows teachers to adapt and adjust their lessons. It also increases students' awareness of their own relevant ideas and experiences. Table 5.5 presents the workshop design using the TfU framework. Table 5.6 provides an overview of design features and the corresponding activities.

Table 5.5 Design framework of Iteration 2

Generative Topic	Features of dialogic science discussion & elicitation discussion
Understanding Goals	**What are the features of dialogic science discussion?** **Teachers will understand that in a dialogic science discussion:** 1) Learners actively listen to each other to make sense of/build on/challenge each other's ideas. 2) Teachers skilfully orchestrate student ideas and move student thinking forward. 3) Learners and teachers draw from a diversity of intellectual resources (e.g., student science ideas, lived experience, ways of using languages, ways of knowing). **What are elicitation discussions?** 1) Teachers will understand that the goal of elicitation discussion is to uncover students' prior knowledge and lived experience. 2) Teachers will understand that elicitation discussions focus on eliciting ideas, which are useful resources for learning, instead of judging whether an idea is right or wrong. **Why conducts elicitation discussions?** 1) Teachers will understand that it is important to elicit student ideas because learning is a process of reconstructing and reorganising what we know, so we need to reveal and talk about these ideas to help students construct knowledge for their understanding. 2) Teachers will understand that eliciting student ideas increase their awareness of their own relevant ideas and experiences to construct understanding and pique students' interest in new learning. 3) Teachers will understand that elicitation discussions provide insight into student thinking and help teachers to be aware of the possible resources and misconceptions that students carry to adapt their lessons. **When to conduct elicitation discussions?** Teachers will understand that elicitation discussion usually happens at the beginning of a unit and can be presented by showing a video or image, doing a demo, or introducing puzzling phenomena to students. **How to lead elicitation discussions?** 1) Teachers will understand that there is a variety of talk moves that they can draw on to facilitate elicitation discussion: - **Think time:** give students time to think and rehearse their talk e.g., partner talk, writing as think time, wait time). - **Probing:** prompt students to make student thinking public. E.g., what experiences have you had with…?"

	- **Gentle follow-ups:** invite students to elaborate on their ideas without judging whether it is right or wrong. The goal is to expand student thinking. E.g., "can you tell me more?", "what do you mean by that?" (Can be non-verbal as well). - **Build-on:** invite students to build on each other's ideas. E.g., "does anyone want to add on what Ava just said?". - **Revoicing:** paraphrase and rebroadcast student ideas to seek clarification or to highlight an important segment of student ideas. E.g., "what I hear you saying is…?" Make sure to leave space for students to agree/disagree/say more - **Encouraging listening:** E.g., "who can rephrase or repeat?" 2) **Promote equity**: Teachers will understand that they can promote equity by: - making the discussion accessible to all students. For example, they can start the discussion by asking students about their observations rather than explanation. - making sure the language is accessible and try to avoid using science terms unless it is explained. - Giving students time to think and rehearse talking about their thinking in small groups. 3) Teachers will understand that it is important to support students to engage with each other's ideas and think together rather than eliciting individual student ideas without connecting them (popcorn discussion). Teachers can do this by using talk moves such as build on and by encouraging listening. 4) Teachers will understand that student ideas should be represented, summarised, and connected into a line of inquiry to provide an anchor to move student thinking forward in subsequent lessons (teachers can model how to summarise and have students to summarise).
Performance of Understanding	Teachers were given a task to elicit student ideas in the virtual classroom as the following: Your students just saw the pictures of "ships in a field" (a puzzling event), and they were all very excited. Your task is to elicit student observations and uncover their initial ideas and related experience about why these ships are in a field.
Ongoing assessment	Teachers conducted collective reflection for their video recordings in small groups in the next workshop.

Table 5.6 Design features and activities of Workshop 2

Design Features	Activity
Community-building (5mins)	**Rose bud thorn**. Teachers share their rose, bud, and thorn in the breakout rooms. Rose = A highlight, success, small win, or something positive that happened this week. Bud = New ideas that have blossomed or something you are looking forward to knowing more about or experiencing. Thorn = A challenge you experienced or something you can use more support
Case studies in guided collaborative inquiry (35mins)	**Visit three classrooms** Drawing on feedback and researcher reflection from iteration 1 on "extra-spection", I intended to widen the dialogic space by presenting multiple cases of teaching practice for teachers to compare, contrast and connect to their own teaching Teachers read transcripts of classroom discussions on the same topic led by three different teachers. The first case is teacher-centred and dominated by IRE discourse pattern. In the second case, the teacher elicited a variety of student ideas but did not build on or make use of them (i.e., popcorn discussion). In the third case, the teacher elicited student ideas, facilitated the interaction among different ideas, and helped students to see the gap in their understanding and move student ideas forward. Teachers discussed the differences they noticed, and they relate these discussions to their own classrooms. Teachers were provided with a task sheet and note catcher on google slide. The material of the activity is adapted from Windschitl et al. (2018).
Mini lecture (10mins)	Researcher provided an overview of what elicitation discussion is, when to use it, and how to facilitate it.
Collective Reflection (25 mins)	Drawing on feedback and researcher reflection from Iteration 1 on "inter-spection, teachers share observations and reflections to identify and develop possible alternative actions. Teachers watched one teacher's simulation recording and discussed the following questions: • Can you recognise student science ideas and lived experience during the discussion? (For example, Ethan made a connection between ground rules of discussion and rules in Minecraft (his lived experience)). • How did the teacher respond? After today's workshop, is there anything you would change? (e.g., any talk moves you can use?)
Mini lecture (5min)	Researcher introduced simulation and task

Simulation Guide (supporting materials)	Teachers were provided with a simulation guide which included the learning goals, the context of the scenario, their task as well as supporting tools, such as a repertoire of talk moves, an annotated transcript of dialogic discussion (with teachers' retrospective thinking) (see Appendix 14)

The co-design meeting took place on June 10th, 2021. We started the co-design meeting by debriefing teachers' feedback and lessons learned from the previous iteration. An overview of the instructional design was presented on an interactive whiteboard during the co-design meeting. Teacher coordinators manipulated sticky notes on the whiteboard to provide new ideas, and suggestions, ask questions, and present challenges, which were incorporated into the design.

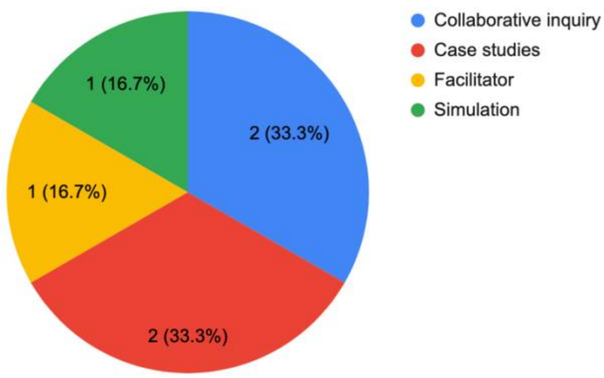
5.7.2 Workshop 2 implementation and feedback

The workshop took place on June 16th, 2021 and lasted for 1 hour and 20 minutes. 10 teachers participated in the workshop. Because of the pandemic, all of the teachers were working from home and teaching remotely. Six teachers provided anonymous feedback via google forms. All of the questions are free response except question 5. I summarised teachers' feedback below.

1) What is helping me to learn in this workshop?

As shown in Figure 5.13, two teachers mentioned collaborative inquiry (33.3%); two teachers mentioned the case studies (33.3%); one teacher mentioned the facilitator (16.7%), and one teacher mentioned the simulation (16.7%).

Figure 5.13 Teachers' mentions of helpful features in Workshop 2



2) What changes are needed in this workshop to improve learning?

Three teachers mentioned that they enjoyed the workshop and did not suggest any change. One teacher suggested more elaboration on the simulation task; one teacher asked for a smaller group in the breakout room, and one teacher suggested having more time (it is unclear what the teacher meant by more time).

3) **At what moment during the workshop did you feel most engaged with what was happening?**

All teachers unanimously said working with their colleagues was the time that they felt most engaged. Three teachers specifically mentioned collaborative inquiry and collective reflection.

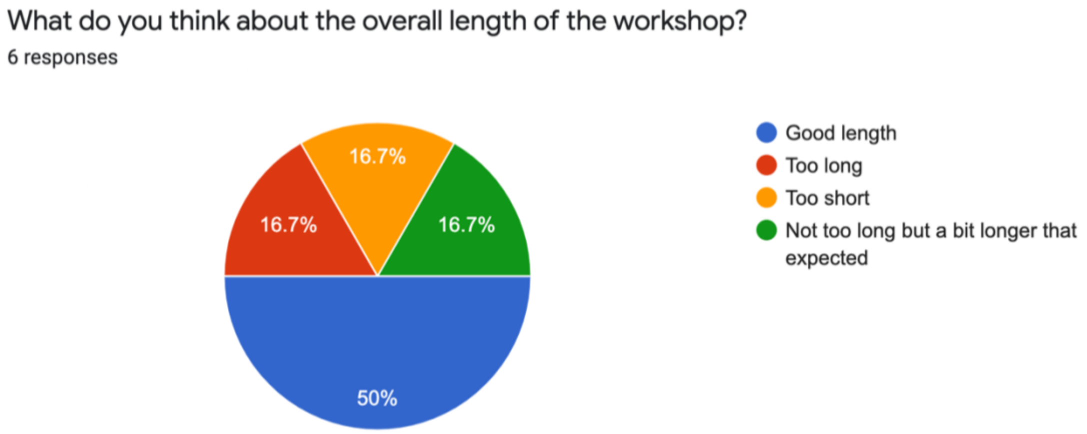
4) **At what moment during the workshop were you most distanced from what was happening?**

Three teachers reported that they felt engaged the whole time. Two teachers mentioned when the collection reflection went too long, they felt they ran out of ideas and started to feel distracted. One teacher mentioned the mini lecture.

5) **What do you think about the overall length of the workshop?**

Teachers had varied opinions about the length of the workshop. Half of the teachers found the workshop a good length. One teacher found it too long, whereas one teacher found it too short. One teacher found the length reasonable but longer than expected (see Figure 5.14).

Figure 5.14 Teachers' feedback on the length of Workshop 2



6) **Anything else you want to add?**

Four teachers answered this question, and all of them expressed enjoyment and gratitude towards the workshop. Two teachers mentioned that they felt comfortable with me and learning in the PD.

Summary of teacher feedback for Workshop 2

In summary, teachers' feedback was generally positive. It is clear that they enjoyed working with their colleagues during the collaborative inquiry working on case studies, which I also observed during the breakout rooms. Teachers engaged in knowledge-based reasoning to compare and contrast three approaches to discussion and distilled the key differences among the three case studies.

Teachers' active processing and construction of understanding were evident in their note catcher. They noted:

> The first was not very generative - it was all centred around a lesson plan, it was more of question and reaching the answer. It started off un-generatively - The answer was given at the start "Yay we just saw a Solar Eclipse." It was good in the sense of timing and following a lesson plan but in the quality of inquiry and discussion it lacked. B was more generative than A but it wasn't as scaffolded by the teacher as C was and so it didn't lead on to anything like inquiry questions in C.

The addition of case studies in collaborative inquiry has worked very well. The note catcher with instructions was also valuable, which allowed teachers to have clear instructions in the group and to have a purposeful discussion. Teachers' enthusiasm about collaborative inquiry made me think that I could merge mini lectures into the collaborative inquiry in the next iteration and test it out. Furthermore, teachers were able to relate their own teaching practice to the three teachers in the case studies, which was evident in their note catcher. For example, teachers wrote: "Teacher B was the most relatable for most of us, as we have felt in the past that our discussions are not conclusive."

According to teachers' notes and my observations in the breakout rooms, teachers were able to provide each other with very valuable feedback for the simulation during collective reflection.
For example, teachers noticed that they could have built the ground rules with students rather than presenting. They also mentioned that they could provide think-time for students at the beginning of the discussion. They also noticed varied lived experiences among students and mentioned talk moves such as revoice to support students to build on each other's ideas. They also noticed the different personalities in the classroom and noted the importance of giving everyone an equitable opportunity to participate. Instead of giving teachers direct feedback as a researcher, the collective reflection time allowed teachers to make use of their learning during the workshop as well as their experience to provide insightful feedback to each other.

Points of refinement:

- Merge mini lecture into collaborative inquiry
- Continue case studies and collective reflection
-

5.7.3 Simulation 2 design

Simulation was extended to12 minutes based on teacher feedback in Simulation 1. Teachers were given a task to lead an elicitation discussion on the topic of "ships in a field" in grade 5 virtual classroom, which is adapted from the Inquiry Project Grade 5 Curriculum (Inquiry Project, 2011)

Teachers were provided with a simulation guide (see Appendix 14) including:

1) Description of the scenarios, tasks and learning goals for teachers and the avatar students
2) Content knowledge (including the national curriculum standards in Pakistan, an overview of the unit, and an explanation of the puzzling event)
3) Pedagogical knowledge (including talk moves, a list of dos and don'ts in elicitation discussion, and a transcript of exemplar elicitation discussion).

The simulation scenario, task and learning goals were as the following:

Simulation scenario:

The discussion takes place at the beginning of an inquiry project on water transformation. "The ship in the field" picture is used as an anchoring event at the beginning of the project, which stimulates students' interest and sustains their intellectual work throughout the project. During this project, students will engage in various investigations to build understanding towards water transformation, both at the visible level and at the particle level. Throughout the project, students will continue revising their initial thinking and gradually construct a coherent and evidence-based explanation for "the ship in the field"[10].

[10] This scenario is adapted from the Inquiry Project Curriculum (Grade 5) https://inquiryproject.terc.edu/curriculum/curriculum5/index.html

Figure 5.15 Aral Sea ship graveyard near Aralsk, Kazakhstan. Photo credit: Zhanat Aithozhin.(Satubaldina, 2018)

The photo of Areal Sea ship graveyard removed for copyright reasons. Copyright holder is Zhanat Aithozhin.

Simulation task:

Your students just saw the pictures of "ships in a field", and they are all very excited. Your task is to elicit student observations and uncover their initial ideas and related experience about why these ships are in a field.

Learning goals for teachers:

1）You will learn to strategically use talk moves to elicit student ideas and to uncover their prior experience.

2）You will practice recognising and making use of students' science ideas and lived experiences during the discussion while maintaining an equitable learning community.

The script is a mix of standard responses and room for improvisation. For example, we suggest that students might have the following nascent science ideas and lived experiences, such as evaporation, global warming, boiling kettle, tide etc. The simulation specialist will deliver the standard elements of the simulation according to three categories (i.e., student science ideas, lived experience, and equity issues) across all simulation sessions. The simulation specialist draws from the suggested ideas within each category to improvise in response to the teacher. Table 5.7 summarises the structure and script of the pilot simulation (for the full script, see Appendix 8).

Table 5.7 Simulation 2 design

	Activity	Sample Script
Introduction with opportunities for recall	- Recall takeaways from the workshop - Remind teacher goals of the simulation	- I know that you have had a workshop with Lydia. In one or two sentences, can you remind me what you learned in the workshop and what your takeaways were?
Preparation	- 2 minutes to prepare for the simulation	
Simulation Round 1	Elicitation discussion: ships in the field	<u>Science ideas: e</u>vaporation, states of water (solid, liquid, gas), saturation, global warming, tide, rust <u>Lived experience: k</u>ettle boiling, rain puddle, dried up salt, fantasy story, Ava's Lake did not dry up in the summer Each idea has suggested lines that simulation specialists can use. Each idea is also followed by a brief student explanation if the teacher prompted the student further. For example: Student response: "I see the ship is rusty." (When asked to say more ➢ students can say "it usually takes time for rust to build up, so it looks like the ship has been there for a long time." <u>Equity in the classroom</u> 1. Ethan's tendency to jump into the discussion 2. Ava being sassy about other students' comments 3. Savannah's reluctance to join in the discussion
Reflection	- Elicit teacher noticing of the multifaceted class (flexible attention) - Deliberately practice talk moves	- What kind of student thinking did you recognise during the simulation, for example, their science ideas, lived experience, class equity? - What talk moves did you use during the discussion? - Let's have our assistant/observer reflect on that moment. What did you see, or what other ideas or suggestions might you add?
Preparation	2 minutes preparation	
Simulation Round 2	Elicitation discussion: ships in the field	Same as round 1
Reflection	- Elicit teacher noticing of the multifaceted class (flexible attention) - Elicit teachers' different perspectives of the same situation	- Welcome back. How do you feel? - Is there anything new you have noticed this time in terms of students' science ideas, lived experience and class equity? - What adjustments or different choices did you make based on the observations from your partner's simulation? - Let's have our assistant/observer reflect. What did you see, or what other ideas or suggestions might you add?

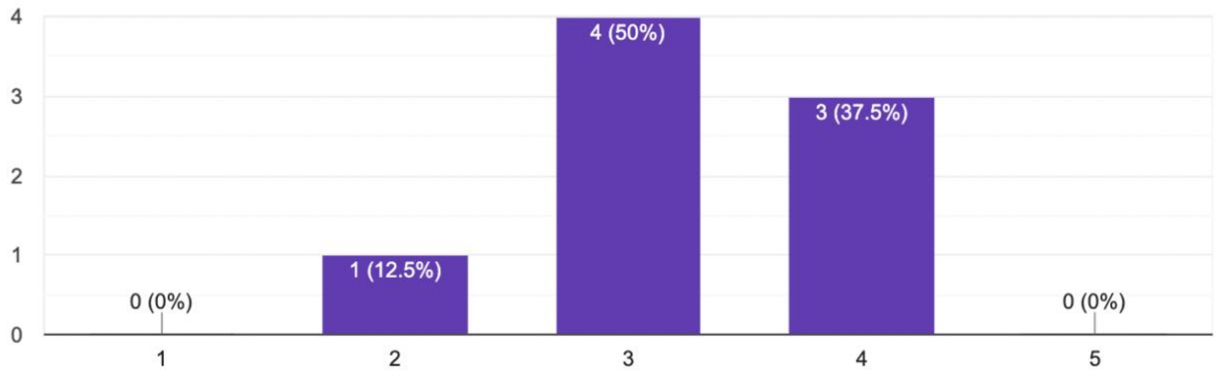
5.7.4 Simulation 2 implementation and feedback

Nine teachers participated in Simulation 2, and eight teachers provided anonymous feedback via google forms. Responses to free-response questions were thematically analysed with emic codes.

1) Cognitive load

Cognitive load was used to gauge how challenged teachers felt in the simulation to make sure the simulations were challenging enough for teachers to progress and at the same time not too challenging that they felt deflated (High-level conjecture 3). As shown in Figure 5.16, four teachers (50%) experienced a cognitive load of 3. Three teachers (37.5%) experienced a relatively high cognitive load, whereas one teacher experienced a relatively low cognitive load (12.5%). The result showed that the simulation fell within a sweet spot that is just challenging enough for teachers to make progress.

Figure 5.16 Teachers' self-reported cognitive load in Simulation 2

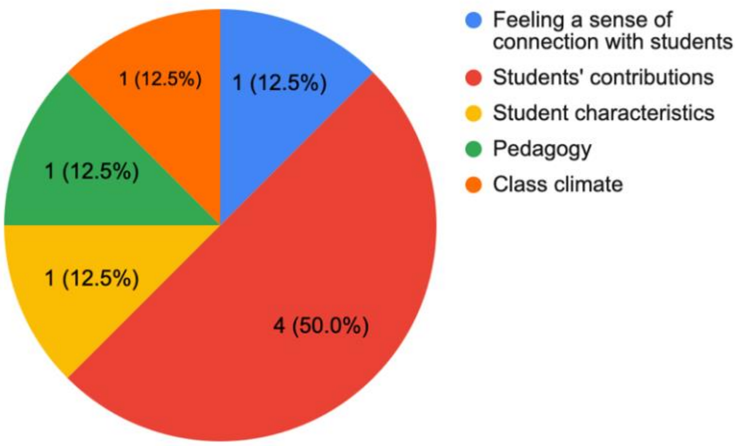


2) Memorable moments

Memorable moments were used to gauge which design feature stood out to teachers and also their general experience in the simulator. As shown in Figure 5.17, four teachers (50%) mentioned student contributions and ideas as the most memorable moments. one teacher mentioned feeling a sense of connection; one teacher focused on the use of talk moves as a part of their pedagogy; one teacher focused on the class climate and how students were building on each other's ideas. According to teachers' responses, their focus was on their interaction with the avatar students, which showed a strong suspension of disbelief in the simulation. This result further demonstrated that teachers were able to develop a sense of relationship and connection with the avatar students.

Teachers were able to treat the simulation as an authentic situation to engage with students for dialogic teaching.

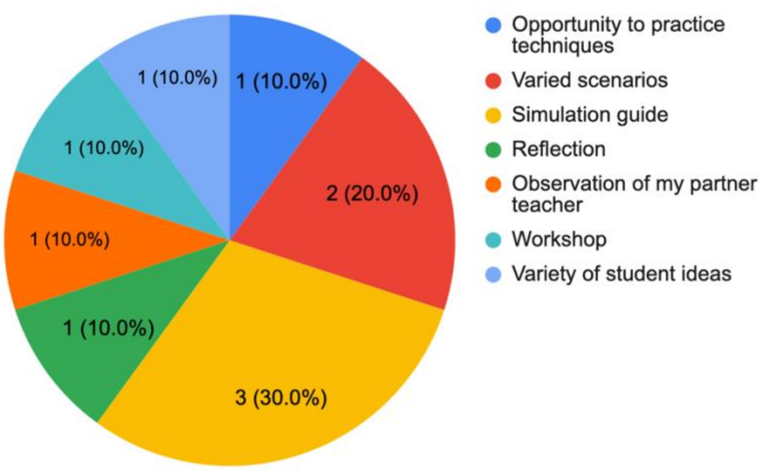
Figure 5.17 Teachers' memorable moments in Simulation 2



3) What is helping me to learn in this simulation?

Teachers mentioned a variety of design features in their responses (see Figure 5.18). 30% of the mentions were about the simulation guide, and 20% of mentions were about the varied scenario. Teachers also mentioned the opportunity to practise, reflect, and observe her partner teacher, and learn from the workshop. Teachers' responses indicate that teachers value the opportunity to enact their learning from the workshop in varied simulated scenarios.

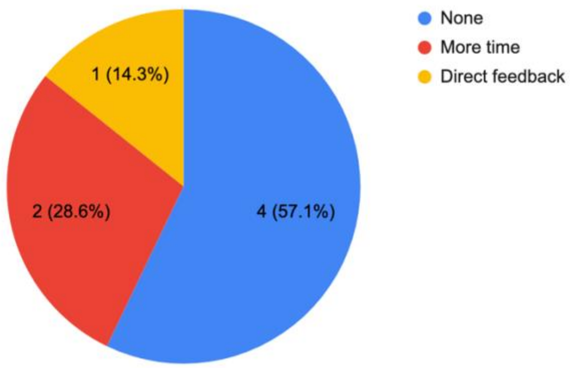
Figure 5.18 Teacher mentions of helpful design features in Simulation 2



4) What changes are needed in this simulation to improve learning?

Four teachers (57.1%) said they did not have suggestions and they were happy with the design. Two teachers (28.6%) asked for more time in the simulation, and one teacher (14.3%) asked for direct feedback. One response was not legible and excluded from the analysis. One teacher noted the limitation in the simulation that they could not circulate the classroom to notice what students were talking about in the small group and observe their work. One way to address this limitation is to provide student work to teachers in advance for them to examine, which was tested in iteration 4.

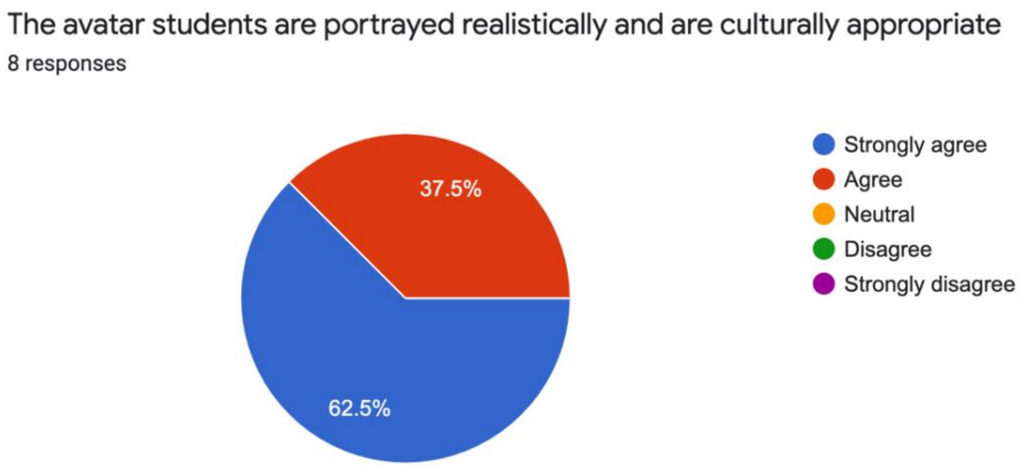
Figure 5.19 Teachers' suggestions for improvement in Simulation 2



5) Cultural appropriateness of avatar students

All of the teachers either agreed (37.5%) or strongly agreed (62.5%) that the avatar students were portrayed realistically and were culturally appropriate, which resonated with the responses of teacher coordinators during the co-design session as well as the pilot run (see Figure 5.20).

Figure 5.20 Cultural appropriateness of the avatar portrayal in Simulation 2



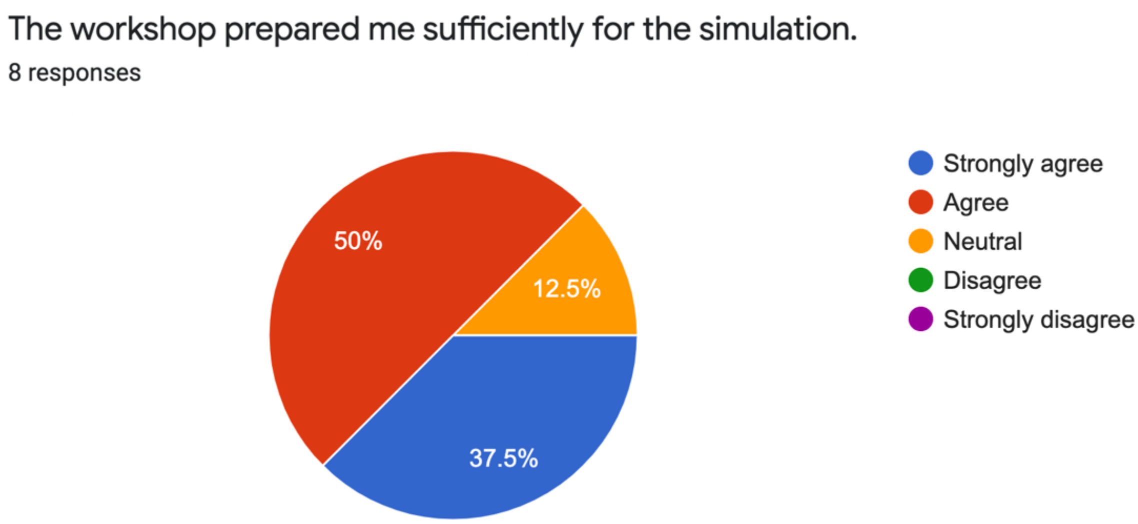
6) What changes in the avatar students would you like to suggest?

Most of the teachers did not suggest changes for avatar students. Two teachers asked the avatar students to speak more slowly, and another asked for lip sync.

7) The workshop prepared me sufficiently for the simulation

Seven teachers (87.5%) agreed or strongly agreed that the workshop prepared them sufficiently for the simulation. One teacher (12.5%) was neutral (see Figure 5.21).

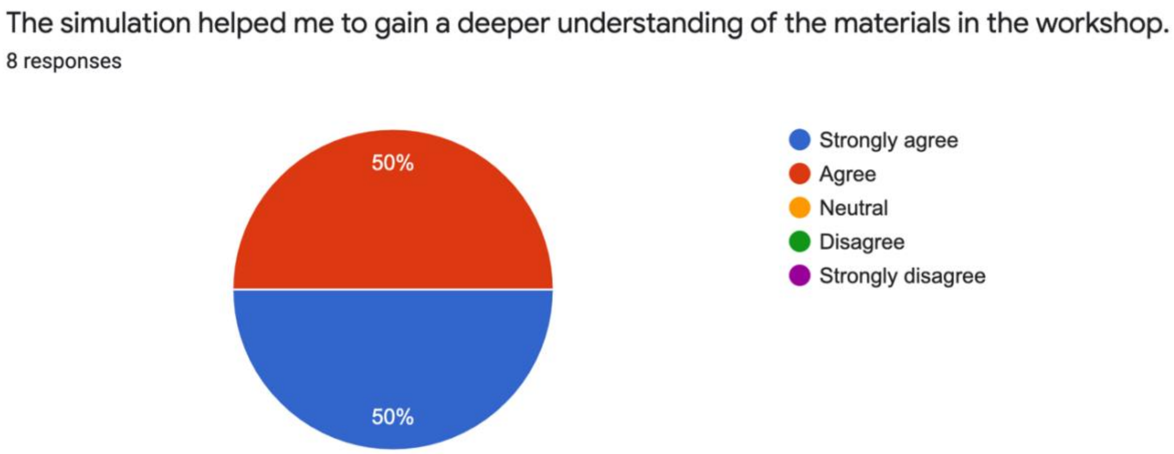
Figure 5.21 Adequacy of workshop as preparation for Simulation 2



8) Simulation as a reinforcement for learning

All of the teachers either agreed (50%) or strongly agreed (50%) that the simulation allowed them to have a deeper understanding of the materials in the workshop (see Figure 5.22).

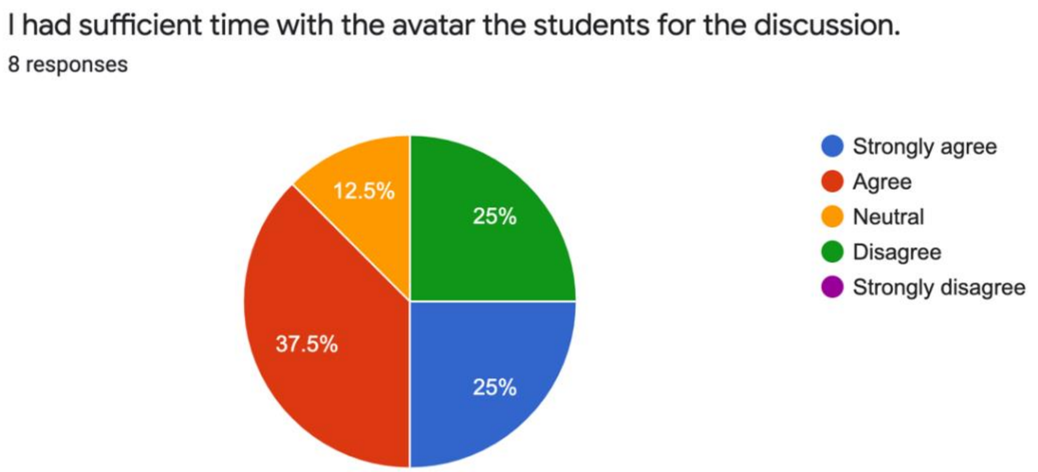
Figure 5.22 Simulation 2 as reinforcement of learning in the workshop



9) Duration of the simulation

Teachers had varied opinions about the duration of the simulation (see Figure 5.23). Most teachers either agreed (37.5%) or strongly agreed (25%) that they have sufficient time with the avatar students. One teacher was neutral (12.5%) whereas two teachers (25%) disagreed.

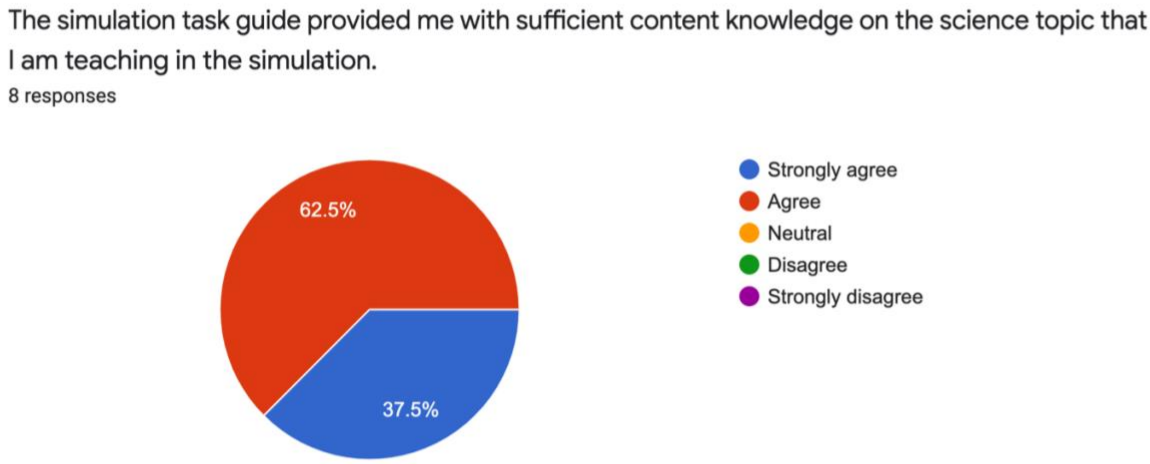
Figure 5.23 Teachers' feedback on the duration of Simulation 2



10) The simulation task guide

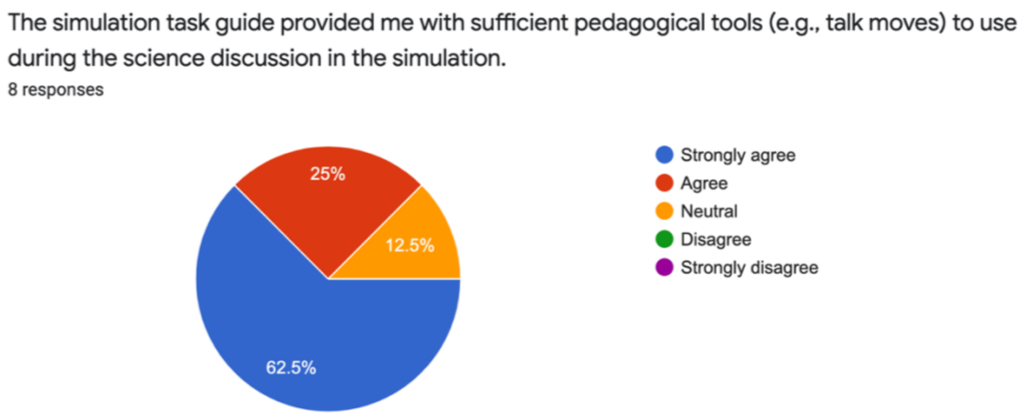
The simulation task guide was a new design feature that was added based on teachers' feedback in the pilot, the purpose is to provide teachers with necessary content knowledge and pedagogical knowledge to prepare for the simulation. All of the teachers either agreed (62.5%) or strongly agreed (37.5%) that the simulation guide provided sufficient knowledge for them to approach the science topic in the simulation (see Figure 5.24).

Figure 5.24 Teachers' feedback on the content knowledge in the Simulation guide



Most of the teachers either agreed (25%) or strongly agreed (62.5%) that the simulation guide provided them with sufficient pedagogical knowledge, and one teacher (12.5%) was neutral (see Figure 5.25).

Figure 5.25 Teachers' feedback on the pedagogical knowledge in the simulation guide



11) What additional support would you have liked to help you prepare for this simulation experience?

One teacher said she would benefit from watching a sample of a real-life class to see how other teachers implemented these tools. One teacher asked for more background knowledge to launch into the conversation, which I interpreted as a more detailed scenario description.

12) Other comments

Two teachers expressed their enjoyment and gratitude for this simulation learning experience. One teacher found this learning experience valuable yet a bit challenging.

Summary of teacher feedback for Simulation 2

According to the feedback, teachers highly valued the learning experience in the simulation and focus on their interaction with the avatar students. The simulation was just challenging enough for teachers to make progress, which reinforced their learning from the workshop. At the same time, the workshop prepared them sufficiently for the simulation, and the addition of a simulation guide was helpful. Furthermore, all of the teachers found the portrayal of students in the simulation culturally appropriate and realistic.

I summarised two points of refinement for the next simulation from my observation and field notes:

1) Provide more detailed scenarios description for teachers
2) Look for examples of dialogic discussion (e.g., video of consolidation discussion).

5.7.5 Reflection as a design researcher

1) Dialogic framing shifts teachers' discourse pattern

In the second simulation, it was surprising to have observed that most of the teachers had already shifted toward a more dialogic discourse pattern. I observed that teachers actively used talk moves to elicit student ideas about the ships in the field. Such observation further challenged the stage-based conception about teachers' responsiveness, i.e., assuming teacher's progress from a stage of not being very responsive, to gradually becoming more responsive (e.g., Empson & Jacobs, 2008). It is implausible that teachers could dramatically shift their discourse pattern only after one simulation session. This is in agreement with Maskiewicz and Winters (2012) that responsiveness is a complex dynamic, rather than a linear progression. It is plausible to consider that the mechanisms that allow such a drastic shift in the simulation were 1) the dialogic framing of the discussion; 2) a repertoire of talk moves. Russ and Luna (2013) showed teachers' epistemological framing could influence their patterns of attention and response. In this second simulation, I observed that teachers adopted a more dialogic discourse pattern that was coherent with the framing of the discussion as eliciting student ideas about a puzzling phenomenon (ships in the field). Furthermore, teachers were equipped with a repertoire of talk moves that were introduced in the workshop and also listed in the simulation guide.

In alignment with previous research on talk moves, I also noticed that teachers could apply talk moves to elicit student ideas but had difficulty in channelling them into productive lines of inquiry (Coffey et al., 2011; Doubler & Paget, 2016; Hennessy & Davies, 2020). Teachers also reflected on the same issue in their own words. For example, one teacher said during the reflection in the simulation:

> I think…the response to the students wasn't building on the conversation…so it wasn't taking them into that direction. There was one moment, the Savannah said that she doesn't even know what evaporation is, that would be a good moment to have Dev to tell her about evaporation, instead the conversation went to global warming. I think based on the bigger topic that was part of the project, they were going a little off topic.

2) Conceptualise discussion as dialogic space

The question is "how can we support teachers to advance student thinking?" Teacher response, the third turn in a typical exchange, plays a critical role in determining whether students have the opportunity to engage in collective sense-making in a dialogic space (Park et al., 2017). What are the possibilities in the third turn? Dialogic space is a useful metaphor because it allows us to think about discussion as a space, where teachers can help to widen, deepen, maintain, and shape. Unlike talk moves that address individual utterance, thinking about the discussion as a space allows teachers to zoom out of the individual utterance and have an overview of the whole dialogue. Following high-level design conjecture 1 (inquiring with teachers rather than prescribing solutions) and the case studies (which teachers highly appraised), I decided to provide teachers with three case studies of classroom discussion, where teachers either widened and deepened, maintained or shut down the dialogic space. Instead of me presenting the metaphor about dialogic space, the case studies would allow teachers to actively form their own understanding and make connections to their own teaching during the collaborative inquiry.

3) Leverage metamorphic resonance to recognise new possibilities of actions

The metaphor of widening, deepening, maintaining and shaping sense-making space is intuitive to understand, which is likely to produce the effect of metaphor resonance for teachers. According to Mason (2002), metaphoric resonance concerns structural resemblances leading to analogical thinking and reasoning (Mason & Davis, 2013). Metaphoric resonance can take place unconsciously or consciously, which could be an important mediating process leading to CR. In a multifaceted classroom full of "blooming, buzzing confusion of sensory data" (Sherin, 2011, p. 4), teachers have to adopt a mix of deliberate consideration and tacit and intuitive knowing. According to Mason and Davis (2013), this tacit and intuitive knowing to act in the moment is active through two mechanisms: metonymic triggering and metaphoric resonance. Metonymy is a figure of speech that substitutes a concept that shares a surface resemblance (e.g., the crown stands for royalty). Mason used the term metonymic trigger to describe the associations arising in us from seeing the surface resemblance. Though metonymic triggers contribute to the unexpected or surprising connections that come to mind, they are difficult to identify because of their idiosyncratic nature (Mason 2002). On the other hand, **metaphoric resonance** concerns structural resemblances leading to analogical thinking and reasoning (Mason & Davis, 2013).

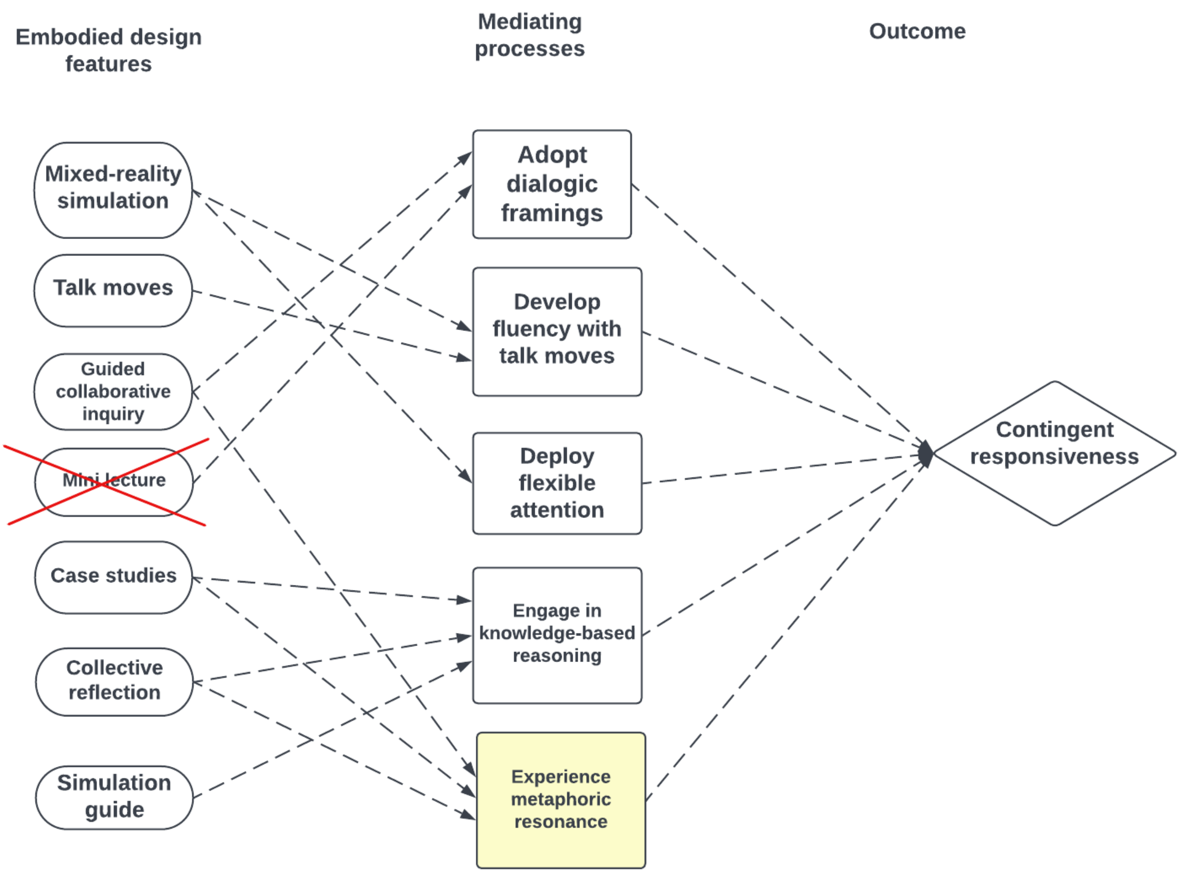
Mason (2002) illustrated how metonymic triggering and metaphoric resonance work with the following example of Ms. Beverly McInnis recounting the story of her experience as a child. When she was in year 6, there were two math groups in her class: 'Rushing Blue Water' and 'Stagnant Green Water'. After getting a low score on a test, her name was put into the green chart. When she became a teacher, she did not use public displays of evaluation for students. Instead, she displayed celebrations of success. Her response to student evaluation is the result of a mix of the metonymic trigger (emotions she experienced as a child) and the metaphoric resonance (the structure of displaying children's names as evaluation). The metonymic triggers are idiosyncratic and difficult to leverage for PD. However, metaphoric resonance (structural resemblance) can be leveraged to help teachers to recognise new possibilities of action.

The PD could leverage metaphoric resonance to create case studies in the workshop and simulation scenarios that have structural resemblance of the teachers' own experience. The goal is for teachers to see themselves through these case studies and simulation scenarios, which hopefully can allow teachers to experience metaphoric resonance in their own classroom when similar situations arise. Furthermore, the structural resemblance of widening, deepening, maintaining, and shaping a dialogic space in different simulation scenarios can potentially evoke metaphoric resonance in teachers to influence their response in the moment.

5.7.6 Refined conjecture map after Iteration 2

Figure 5.26 presents an updated version of the conjecture map after Iteration 2. Mini lecture was removed as a design feature. Added mediating process was highlighted in yellow. The dotted lines represent the tentative nature of the conjectures.

Figure 5.26 Refined conjecture map after Iteration 2



5.8 Iteration 3: Sense-making space & consolidation discussion

In the previous iteration, teacher gained a macro-level overview about productive dialogic science discussions and deployed flexible attention in the simulation to attend to students' science ideas, lived experience, and classroom equity. As shown in simulation 2, teachers could enhance student participation and elicit student ideas using a set of talk moves. However, the challenge is to make use of student ideas to move their thinking forward. The PD addressed this challenge by conceptualising discussion as a dialogic space, which I referred to as 'sense-making space' during the workshop with teachers. I chose to use the term sense-making to highlight the scientific practice of sense-making, which is defined as "wrestling with ideas, language, experiences, and perspectives to figure out how and why the world works" (Schwarz et al., 2021, pp. 113–114). In this workshop, the notion of sense-making space is introduced to teachers through three case studies. In workshop 3, the goal is to provide teachers with a micro-level view, zooming into the third turn of teacher's response to promote collective sense-making and classroom equity. The notion of sense-making is introduced along the consolidation discussion as a dialogic framing.

Consolidation discussion often happens at the end of an inquiry activity (e.g., investigation, experiment). It is found that many primary science teachers tend to focus on doing the hands-on 'activity that works' without unpacking the underlying conceptual understanding afterwards (Appleton, 2003). The goal of consolidation discussion is to help students connect that they learned during inquiry activities to their initial ideas and the big science ideas, and to the larger puzzling science event (Windschitl et al., 2018). In other words, consolidation discussion helps students solidify their understanding of the activity, so they understand what they did, why they did it and connect what they found to develop conceptual understanding. Consolidation discussion is very important because it allows students to move beyond simply doing hands-on activities and investigations for the sake of it.

5.8.1 Workshop 3 design

presents the overall design framework for Iteration 3 using the TfU framework. Table 5.9 provides an overview of design features and the corresponding activities.

Table 5.8 Design framework of Iteration 3

<table>
<tr><th></th><th></th></tr>
<tr><td>Generative Topic</td><td>Consolidation discussions: Connect inquiry activities to big scientific ideas</td></tr>
<tr><td>Understanding Goals</td><td>Sense-making space

1) Science discussion can be conceptualised as a space for collective sense-making.
2) Sense-making refers to “wrestling with ideas, language, experiences, and perspectives to figure out how and why the world works” (Schwarz et al., 2021, pp. 113–114).
3) Response to students can be conceptualised into opening, widening, deepening, maintaining, and closing sense-making space.

Consolidation discussion

What

1) Teachers will understand that consolidation discussions are used to help students make connections between an activity and the larger scientific ideas. In other words, to solidify understanding of key science concepts and processes.
2) Teachers will understand that consolidation discussion evolves around three questions “what you did”, “why you did it” and “what you found out”.

Why

3) Teachers will understand that consolidation discussion is important because it allows students to move beyond the activity itself to develop conceptual understanding.
4) Teachers can gain insight of student understanding and reasoning during consolidation discussions.

When

5) Teachers will understand that consolidation discussions usually happen at the end of an inquiry activity (e.g., investigation, experiment).

How

6) Teachers will understand that there are a variety of talk moves that they can draw on to facilitate consolidation discussion.
- Think time: give students time to think and rehearse their talk e.g., partner talk, writing as think time, wait time)
- Probing: prompt students to make student thinking public. E.g., “now that we’ve finished with the mini-lake activity, can we talk what you did in the activity and why you did it?”
- Pressing: press student for reasoning and evidence to go deeper to deeper. Different from gentle follow-ups, where the goal is to expand student thinking. The goal of pressing is to deepen student thinking. E.g., “what do you mean by dissolving?”
- Build-on: invite students to build on each other’s ideas. E.g., “does anyone want to add on what Ava just said?”.</td></tr>
</table>

	- **Revoicing**: paraphrase and rebroadcast student ideas to seek clarification or to highlight an important segment of student ideas. E.g., "What I hear you saying is…?", "are you saying…?" - **Encouraging listening:** E.g., "Who can rephrase or repeat?" - **Focus:** it is easy for students to embark on irrelevant topics during the discussion, refocus students' attention to the question/task. E.g., "how is your comment connected to the phenomenon we are looking at?" **Highlighted in red is what is new to the talk move toolkit from the last session** 7) **Promote equity:** Teachers will understand that they can promote equity by - inviting multiple voices and ideas in the whole group and giving all students a chance to express their thinking in small groups. - encouraging students to engage with and respond to each other's ideas. - Assigning participation roles, jig-saw activities, structured turn-and-talks. 8) Teachers will understand that it is important to facilitate students to think deeper by challenging their thinking rather than "funnelling" students towards the "correct" answer.
Performance of Understanding	Teachers provided with a simulation task to consolidate student understanding after an inquiry activity.
Ongoing assessment	Teachers will collectively reflect on their performance in simulation 3 in small groups during Workshop 4.

Table 5.9 Design features and activities of workshop 3

Design Features	Activity
Recall (5mins)	**Have teachers actively recall their learning in the PD and check each other's posts in an interactive whiteboard, Padlet.**
Collaborative inquiry and case studies (30mins)	**Visit three discussions** Teachers worked in small groups on the three classroom episodes where teachers either widened or deepened, maintained or shut down the sense-making space. Episode 1: Brianna widening and deepening sense-making space Episode 2: Jeanine maintaining sense-making space Episode 3: Celine shutting down sense-making space **Teachers recorded in their note catcher:** 1) In your own words, explain what sense-making means. 2) From reading the transcripts, what do you think it means to open up, widen, deepen, maintain, and shut down sense-making space? What did the teachers do? Use specific examples from the transcript. 3) What are the similarities and differences you noticed among the three teachers? 4) Can you think of moments in your classroom discussion that you either opened, widened, deepened, maintained, or shut down sense-making space?

Collective Reflection (25 mins)	In your breakout room, take turns to show your simulation recording. While you watch the recording, you each identify moments that you think the teacher either opened up, deepened, widened, maintained, or shut down sense-making space. 1. Compare and contrast the moments you identified and explain to each other your reasoning (e.g., why do you think this is a moment that deepened sense-making space? What did the teacher do and what happened in the discussion that suggested that?) 2. Are there any discrepancy/differences between the moments you each identified? If so, what did you learn from these differences 3. What would you do differently if you could redo the simulation? 4. What feedback/advice would you give to your colleague?
Prepare for the simulation (15min)	To familiarise with the background of the simulation scenarios and scientific concepts. To make plans for the simulation scenario,

5.8.2 Workshop 3 implementation and feedback

The workshop took place on Oct. 14th, 2021. Eight teachers participated in the workshop. Three teachers left the school in the summer, and three new teachers came on board. At the time of the workshop, the school had resumed face-to-face teaching, so all the teachers joined on campus. Instead of joining individually from their own laptop (like in Workshop 1 & 2), teachers sat in groups and shared the laptop. On the workshop day, there were some scheduling issues from the school, and some of the teachers were still supervising students when the workshop was supposed to take place. Therefore, the workshop was delayed for more than thirty minutes, and teachers started to join gradually after. The workshop was scheduled for 2 hours and lasted 1 hour and 30 minutes. As a result, teachers did not have enough time to go through all of the activities of the workshop.

To support the new teachers to come on board, each new teacher was paired up with a teacher who had previously participated in the workshops and simulations to complete the remaining activities asynchronously, i.e., collective reflection and collaborative inquiry on consolidation discussion. A graphic organiser is included to support observing/assistant teacher to record their observation and reflection when watching the simulation recording. The graphic organiser specifically directed teachers' attention to moments where the lead teacher either opened, widened, deepened, maintained, shaped, or closed the sense-making space (see Appendix 9). The activities were reformatted as workbooks on google slides, which also served as a note catcher for teachers.

Teacher feedback for Workshop 3

Only three teachers answered the feedback forms, which I think partly had to do with the scheduling issue on the day of the workshop. Teachers had to leave right after the workshop, so many of them did not have the chance to fill out the feedback form after the workshop.

1) **What are my top 3 takeaways from this workshop?**

Despite the small number of responses, there is strong evidence of learning from teachers. For example, teachers reflected when they could use consolidation discussion in their own teaching and apply talk moves in their own class. Teachers also adopted the metaphor of dialogic space and talked about the importance of widening and deepening the discussion.

2) **Did today's workshop help you to change your way of thinking about leading science discussions? If so, use the prompt "I used to think...; I now think..." to express what has changed for you.**

Teachers mentioned that they previously focused only on maintaining the sense-making and that they will try to focus on widening and deepening it.

3) **What changes are needed in this workshop to improve learning?**

All of the teachers said they think the workshop was too long after a day of teaching at the school.

4) **At what moment during the workshop did you feel most engaged with what was happening?**

Teachers mentioned working in the breakout rooms with their colleagues.

5) **At what moment during the workshop were you most distanced from what was happening?**

One teacher mentioned towards the end, and it was not clear what she meant by this. One teacher said she felt engaged the whole time.

Summary of teacher feedback on Workshop 3

Compared to previous iterations, the feedback from teachers was limited. Despite the scheduling problem on the day, there was evidence of teacher learning, especially during the collaborative inquiry. Teachers applied the metaphor of sense-making space in their feedback form as well as their note catcher. All of the teachers found the workshop too long, which was not the case in the first two iterations. Teachers said they found it hard to focus for a long time after a day of teaching, which is very reasonable given the high intellectual and physical demands of teaching. The school has designated weekly PD time for teachers. Due to the glitch in the scheduling, the PD took place after a regular teaching day, which made it very demanding for teachers to engage in the PD. This incident illustrates the importance of providing teachers with time and space for professional development. Furthermore, since teachers were back on campus, they were sitting in groups and sharing one laptop during the PD rather than joining individually from their laptop. Such hybrid setup made it difficult for me listen in to what teachers were discussing and to participate in teachers' discussion.

5.8.3 Simulation 3 design

The goal of the simulation is for teachers to widen, deepen, maintain, and shape a consolidation discussion. The scenario was built upon the previous simulation to approximate a sequence of science instruction in real life, where an elicitation discussion is followed by an experimentation or investigation. The scenario is set after a series of student experiments. The simulation was further extended to 15-20 minutes.

As in the previous iteration, teachers were provided with a simulation guide that includes:

1) A detailed description of the scenarios, tasks and learning goals for teachers and the avatar students
2) Content knowledge (detailed description of students' experiments, explanation of scientific concepts in the simulation, and further resources)
3) Pedagogical knowledge (A list of talk moves).

The simulation task and learning goals were as the following:

Simulation task

Your task is to lead a consolidation discussion at the end of the mini-lake investigation to solidify student understanding of the investigation process and make connections to the underlying science concepts and the larger puzzles that students try to solve, i.e., how did the ship end up in the field? Remember consolidation discussion usually revolves around four questions:

1) What did you do?
2) Why did you do it?
3) What did you find out?
4) How does it connect to the larger scientific ideas and the puzzle at the beginning of the inquiry?

Simulation learning goals:

1）You will practice using various talk moves to open up, widen, deepen, maintain, and close sense-making space for students.

2）You will exercise your professional judgment to decide when to widen, deepen, maintain, and close sense-making space.

Graphic organiser

The same graphic organiser in the asynchronous task was included in the simulation to support observing/assistant teachers to record their observations and reflections. In this simulation, the graphic organiser specifically directed teachers' attention to moments where the lead teacher either opened, widened, deepened, maintained, shaped, or closed the sense-making space.

The script is a mix of standard responses and room for improvisation. Table 5.10 summarised the structure and script of Simulation 3.

Table 5.10 Simulation 3 design

	Activity	Sample Script
Introduction with opportunities for recall	- Recall takeaways from the workshop - Remind teacher goals of the simulation	- I know that you have had a workshop with Lydia. In one or two sentences, can you remind me what you learned in the workshop and what your takeaways were?
Preparation	- 2 minutes to prepare for the simulation	
Simulation Round 1	Elicitation discussion: ships in the field	Science ideas: dissolving, evaporation, condensation, global warming Each idea is developed into a mini script with suggested student lines and possible teachers' responses. For example: Jasmine: The salt disappeared when we put it into water. If the teacher pressed the response, Jasmine would offer more explanations. Jasmine: I mean when we put salt initially, we can see the salt. But as we stir, it disappeared. Teacher: Where did the salt go? Jasmine: The salt is still there, but we just couldn't see it. Equity in the classroom Ethan's tendency to jump into the discussion Ava being sassy about other students' comments Savannah's reluctance to join in the discussion
Reflection	- Elicit teacher noticing of the multifaceted class (flexible attention) - Deliberately practice talk moves	- Try to recall a moment in your discussion that you either opened up, deepened, widened, maintained or shut down sense-making space. What did you say or do at that moment? Why did you make that decision? - Let's have our assistant/observer reflect on that moment. Did you notice the same thing in your colleague's reflection? Tell us one sense-making space that you noticed.
Preparation	2 minutes preparation	
Simulation Round 2	Elicitation discussion: ships in the field	Same as round 1
Reflection	- Elicit teacher noticing of the multifaceted class (flexible attention) - Elicit teachers' different perspectives of the same situation	- Is anything new you have noticed this time about how your talk moves helped to open up, deepen, or close student thinking? - What adjustments or different choices did you make based on the observations from your partner's simulation? - Let's have our assistant/observer reflect. What did you see, or what other ideas or suggestions might you add?

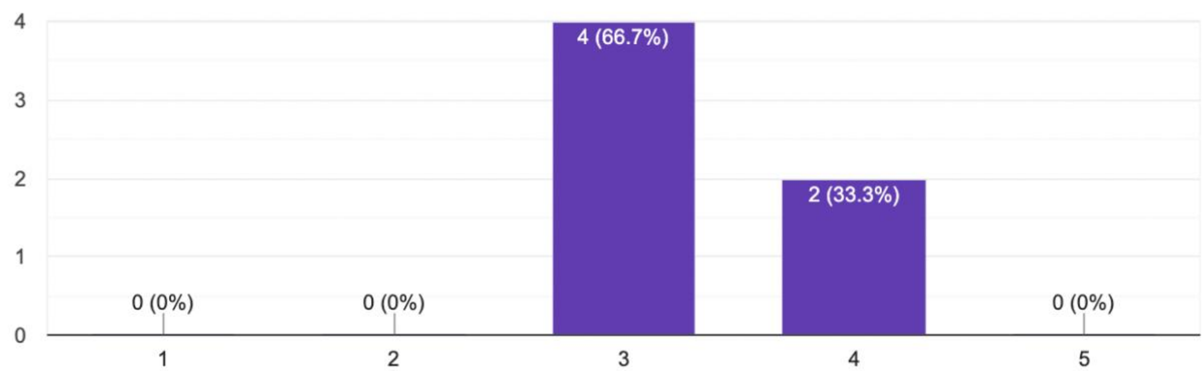
5.8.4 Simulation 3 implementation and feedback

Seven teachers participated in the simulation,[11] and six teachers provided anonymous feedback via google forms. Responses to free-response questions were thematically analysed with emic codes.

1) Cognitive load

Cognitive load was used to gauge how challenged teachers felt in the simulation to make sure the simulations were challenging enough for teachers to progress and at the same time not too challenging that they feel discouraged (High-level conjecture 3). Four teachers (66.7%) experienced a cognitive load of 3. Two teachers (33.3%) experienced a relatively high cognitive load. Given that two new teachers participated in the simulation for the very first time, it is not surprisingly that some of them experienced a relatively high cognitive load. However, the feedback form was anonymous, it was not certain which teachers experienced cognitive load of 4. Nonetheless, overall, the difficulty of the simulation allows teachers to work at the edge of their competency.

Figure 5.27 Teachers' self-reported cognitive load in Simulation 3



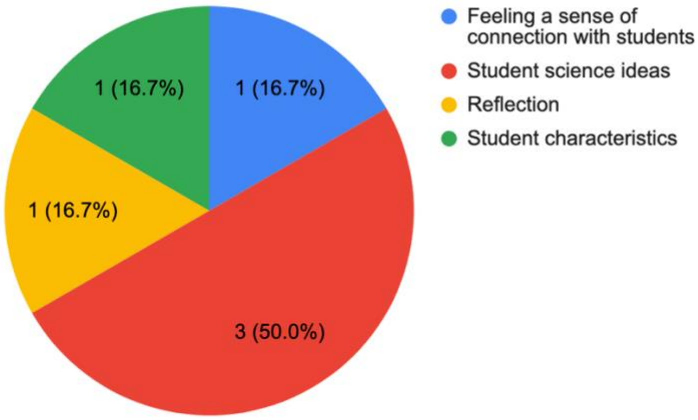
2) Memorable moments

Memorable moments were used to gauge which design feature stood out to teachers and also their general experience in the simulator. Three teachers (50%) mentioned student science ideas as the most memorable moments, one teacher mentioned feeling a sense of connection; one teacher

[11] One teacher did attend the simulation due to personal circumstances.

mentioned the opportunity to reflect on her own pedagogy; one teacher focused on the variety of student personalities in the classroom (See Figure 5.28).

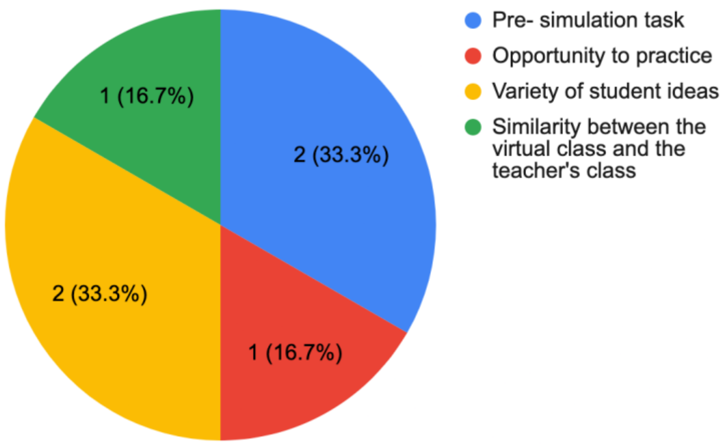
Figure 5.28 Teachers' memorable moments in Simulation 3



3) What is helping me to learn in this simulation?

Teachers mentioned a variety of design features in their responses. Two teachers mentioned pre-simulation tasks and two teachers mentioned the variety of student ideas. Teachers also mentioned the opportunity to practice. One teacher mentioned she noticed the virtual class is similar to her own class, which prepared her to be ready when similar situations arise (see Figure 5.29).

Figure 5.29 Teacher mentions of helpful design features in Simulation 3



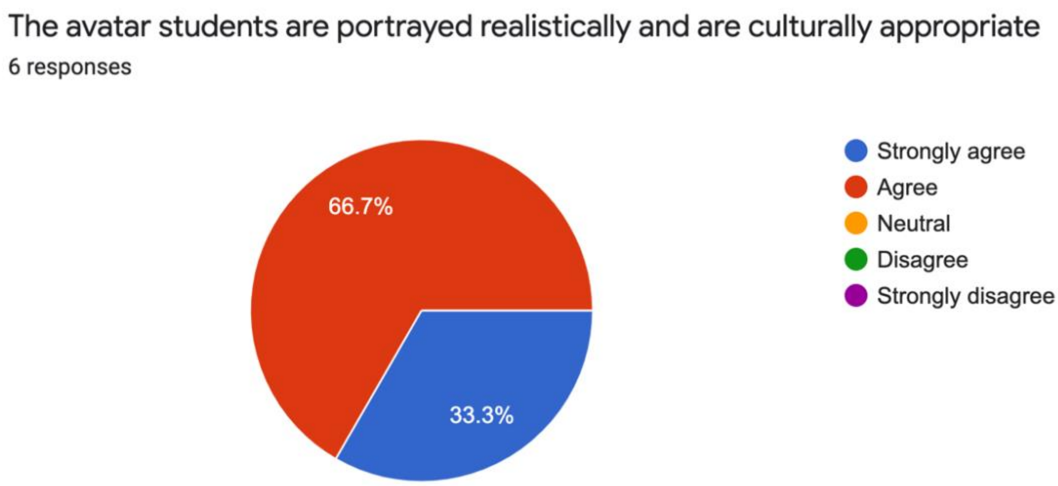
4) What changes are needed in this simulation to improve learning?

Four teachers responded to this question. Two teachers said they did not have any suggestions and they were happy with the design. One teacher mentioned that she would like to have a whiteboard during the discussion. One teacher said there is a discrepancy between what she thought students knew and students' demonstrated understanding, which I will address by providing teachers with students' work, so they have clear knowledge about where students currently stand in terms of their understanding. Having a shared space to record student ideas to make their thinking visible is helpful in leading productive science discussions. However, this is not yet possible in the simulation environment. I am going to report this feedback to the developer at the end of the study.

5) Cultural appropriateness of avatar students

All of the teachers either agreed or strongly agreed that the avatar students were portrayed realistically and were culturally appropriate, which resonates with the responses of teacher coordinators during the co-design session, and the feedback of the previous two iterations (See Figure 5.30).

Figure 5.30 Cultural appropriateness of the avatar portrayal



6) What changes in the avatar students would you like to suggest?

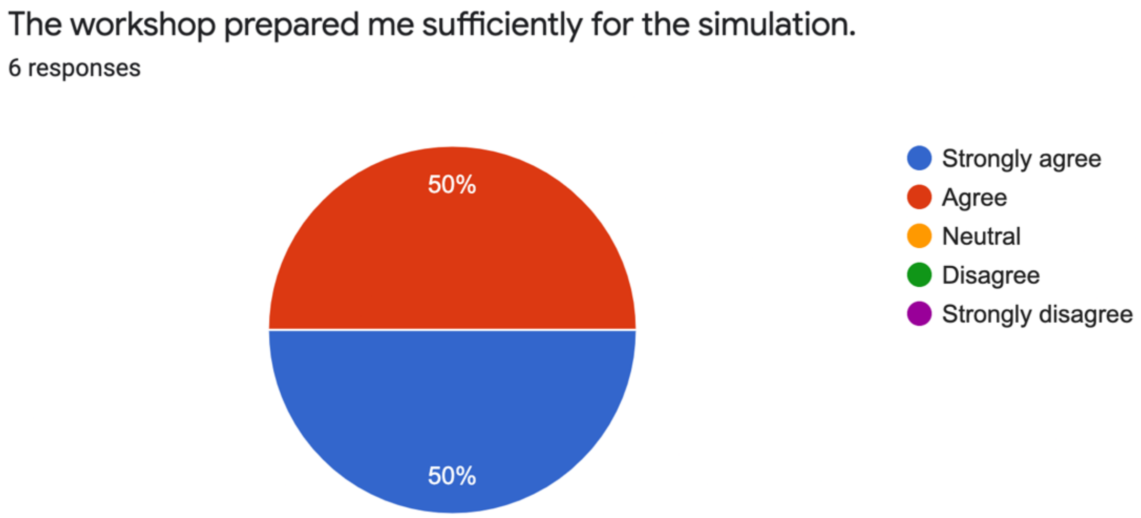
One teacher suggested the avatar students should have more realistic voices. One teacher found the avatars were very similar to their own students.

7) The workshop prepared me sufficiently for the simulation

As shown in

Figure 5.31, all of the teachers agreed (50%) or strongly agreed (50%) that the workshop prepared them sufficiently for the simulation.

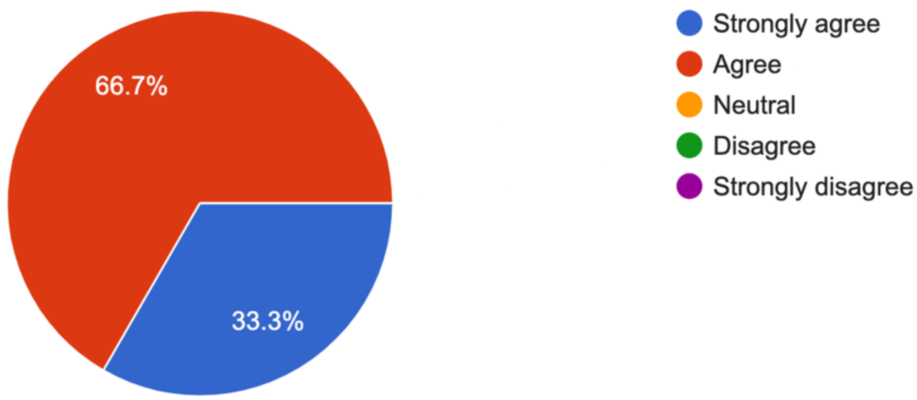
Figure 5.31 Adequacy of the workshop as preparation for Simulation 3



8) Simulation as a reinforcement for learning

All of the teachers either agreed (33.3%) or strongly agreed (66.7%) the simulation allowed them to have a deeper understanding of the materials in the workshop (See Figure 5.32).

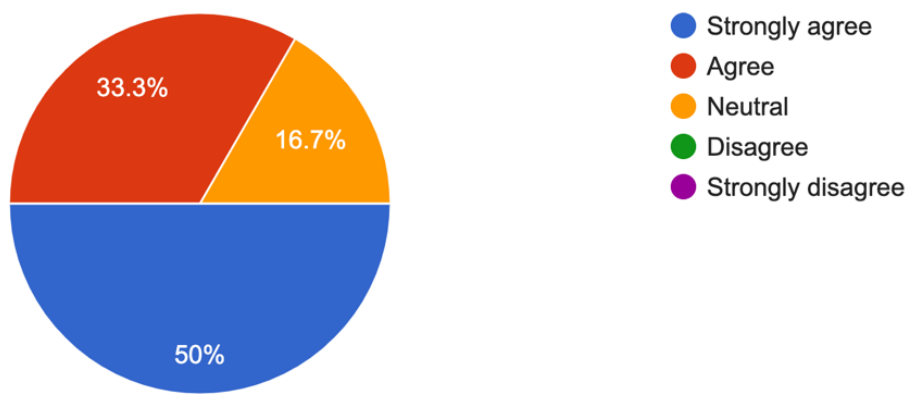
Figure 5.32 Simulation 3 as reinforcement for the workshop



9) Duration of the simulation

Most of the teachers (83.3%) thought they had sufficient time with the avatar students for the discussion (See Figure 5.33).

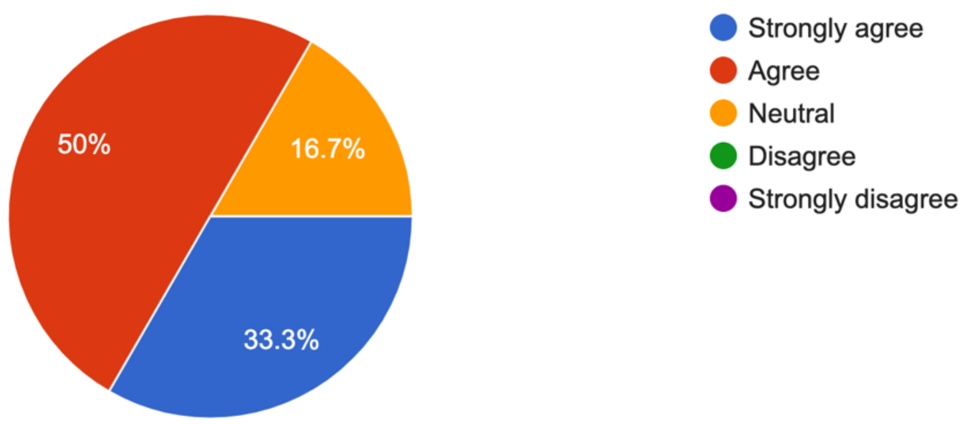
Figure 5.33 Teachers' feedback on the duration of Simulation 3



10) The simulation task guide

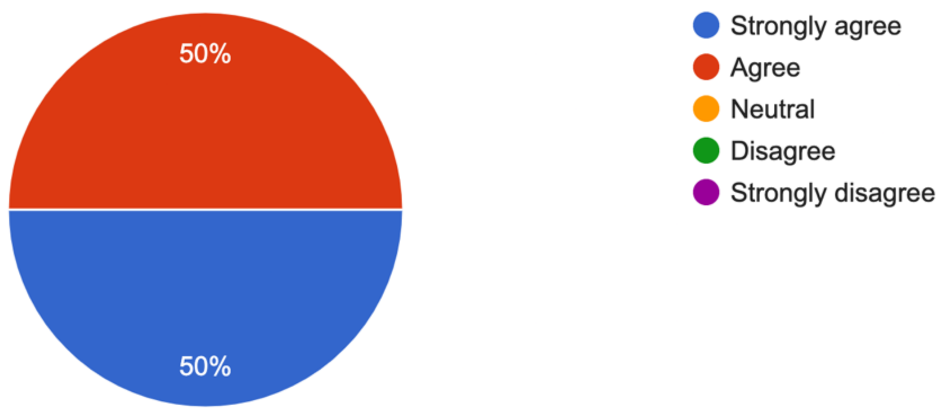
Most of the teachers (83.3%) found that the simulation guide provided sufficient content knowledge for them to approach the science topic (See Figure 5.34).

Figure 5.34 Teachers' feedback on the content knowledge in the simulation guide



As shown in Figure 5.35, All of the teachers either agreed (50%) or strongly agreed (50%) that the simulation guide provided them with sufficient pedagogical knowledge.

Figure 5.35 Teachers' feedback on the pedagogical knowledge in the simulation guide



11) What additional support would you have liked to help you prepare for this simulation experience?

Two teachers said that the materials provided were sufficient. One teacher mentioned that she would like to have a count-down timer for the discussion. One teacher mentioned that she would like to have more details on students' prior knowledge.

12) Other comments

One teacher expressed her appreciation towards the PD. The teacher wrote:

> The whole workshop is quite informative, and I am learning things that I was unaware of earlier like elicitation discussion, consolidation discussion and talk moves.

Summary of teacher feedback for Simulation 3

The difficulty of the simulation is suitable for teachers to make progress. There is strong suspension of disbelief in the simulation and teachers were able to connect with the avatar students on a personal level. Teachers value the diversity of student personalities and ideas, which they thought resemble their real-life classroom. Teachers highly value the simulation as an opportunity to enact and reinforce their learning in the workshop. The avatar students were portrayed realistically and were culturally appropriate. Most of the teachers found the simulation guide helpful in providing them with content and pedagogical knowledge for the simulation. One teacher reported a discrepancy between her expectation of student understanding and what students know in the simulation. Teachers reported certain features they would like the simulation to have, such as a count-down timer and whiteboard.

5.8.5 Reflection as a design researcher

So far, I have observed that teachers were able to apply talk moves to elicit student ideas and conceptualise discussion as a sense-making space, in which they could widen, deepen, maintain, and shape. The metaphor of a space is intuitive to understand

1) Length of the workshop

Teachers reported that the workshop (which was originally designed for 2 hours) was long. To shorten to the workshop, I could redesign part of the workshop into asynchronous activities that teachers can do in their own time before the workshop. It is important to make sure that the asynchronous activities are interactive and engaging for teachers. I decided to test out an asynchronous format of pre-work preparation using Typeform (which is a survey tool), but it could be adapted for learning purposes.

2) Knowledge-based reasoning and student work

One of the feedback teachers provided was that there was a discrepancy between what she expected students to know and students' demonstrated understanding in the simulation. I think this can be addressed by providing teachers with student work in advance. So far, the simulation guide has included the description of the simulation scenario, task, learning goals, a repertoire of content knowledge and pedagogical tools. I think it could be beneficial to include pedagogical content knowledge in combination with students' work, to support teachers to notice students' disciplinary ideas. Teachers' knowledge-based reasoning has both content-specific and content-generic components. Sometimes, teachers draw on discipline-specific expertise as science teachers whereas other times they draw on general pedagogical knowledge. So far, teachers' knowledge-based reasoning has focused on pedagogical knowledge. In the next iteration, I will incorporate PCK into the simulation guide in the context of student work to help teachers reason about student thinking.

3) **Organise talk moves into a dialogue-focused framework**

Michaels and O'Connor (2015) conceptualised them as talk moves and categorised them into four foundational goals. These four foundational goals focus on responding to each individual's utterance. Teachers are oriented by the utterance of the individual learners rather than the larger picture of the whole dialogue during PD, these four goals are often presented as challenges teachers often encounter when leading discussions. For example, what can teachers do when they didn't understand what students said and do not want to embarrass the students. The "say more" talk moves can be helpful in this situation to ask students to elaborate on their thinking. Conceptualising talk moves in terms of foundational goals has proven helpful for teachers to organise the talk moves and deploy them during challenging moments in a discussion. However, such organisation of talk moves does not necessarily address the orchestration of talk and how to advance student thinking.

Orchestration of talk and advancement of student ideas require a shift away from individual student ideas to the collection of ideas in a dialogic space. In other words, teachers need to pay attention to each turn of talk while having the larger picture in mind to help students collectively improve the dialogue and move student thinking forward. The view of the 'large picture' is missing in the foundational goals that are utterance-focused. I proposed reframing talk moves into a dialogue-focused framework and organising talk moves according to its dialogic functions, that is to widen, deepen, maintain, and shape dialogic space.

5.8.6 Refined conjecture map after Iteration 3

Points of refinement for the workshop:

1) Add guided individual inquiry (asynchronous) to offload some of the activities to shorten the workshop duration. Make an asynchronous activity interactive and engaging using Typeform.
2) Introduce to teachers about organising talk moves into dialogic function.

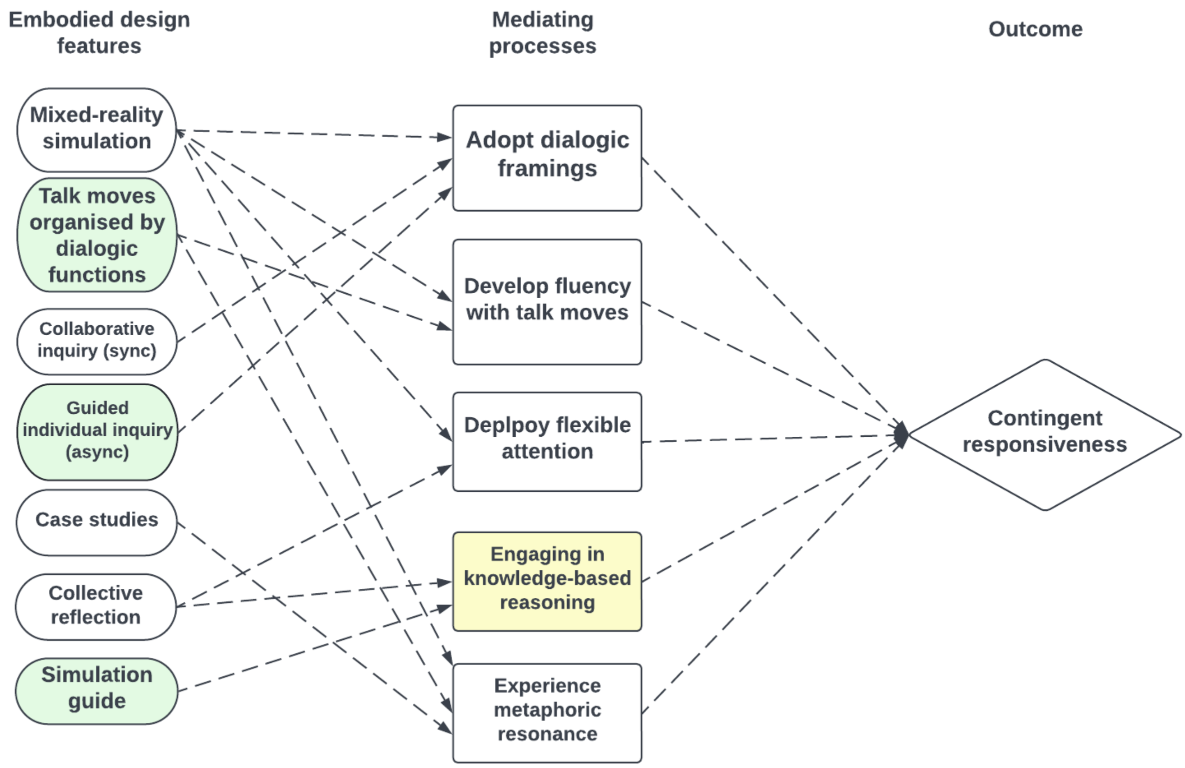
Points of refinement for simulation:

1) Include student work in the simulation guide to illustrate students' understanding and knowledge.
2) Incorporate commentary in student work and highlight the pedagogical content knowledge involved

3) Report to the developer about features that teachers would appreciate: whiteboard, count-down timer

Figure 5.36 summarises the refinement of the design in form of a conjecture map. Green boxes represent refined design features, and the yellow box represents the refined mediating process. The dotted lines represent the tentative nature of the conjectures.

Figure 5.36 Refined conjecture map after Iteration3



5.9 Iteration 4: Moving student ideas forward & explanation discussion

So far, teachers have learned about features of dialogic discussions, using talk moves to elicit student ideas, and conceptualising discussion as a sense-making space in which they can widen, deepen, maintain, and shape. In this iteration, the focus is on scientific practice and moving student thinking forward. The workshop aims to support teachers to reflect on the nature of science, the goal of science education, and how to advance student thinking in dialogic teaching. Explanation discussions can happen at the end of an experiment or after a series of investigations, therefore, they can take place in the middle or towards the end of a unit. During the explanation discussion, students make use of scientific concepts and principles, identify evidence, and explain reasons to justify their claims, which is often intertwined with scientific argumentation. Science argumentation is not about "winning" the argument, rather the goal is to get closer to a more powerful explanatory model by examining each other's evidence and reasoning.

5.9.1 Workshop 4 design

Table 5.11 presents the overall PD design using the TfU framework .Table 5.12 provides an overview of design features and the corresponding activities in workshop.

Table 5.11 Design framework of Iteration 4

Generative Topic	Moving student thinking forward and explanation discussion
Understanding Goals	**Moving student thinking forward:** 1) Teachers will understand the progressive and dialogic nature of science and view learning science as a process of student sense-making. 2) Teachers will understand that leading productive discussion requires both "zooming in" and "zooming out". Like a road trip, teachers need to pay attention to each turn and the overall direction. Teachers will use the following prompts to think about advancing student thinking. At this moment, should I widen, deepen, maintain, close, or shape the sense-making space? **Explanation discussion** **What** 1) Teachers will understand that explanation discussions are used to help students to use evidence and reasoning to construct explanations for their findings and justify their claims.

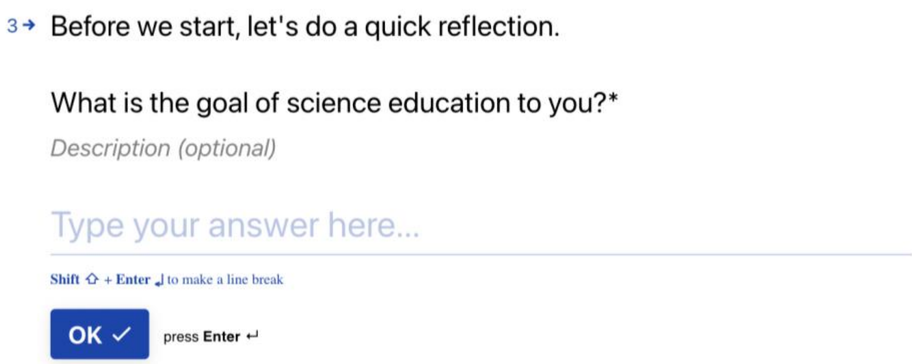
	2) Teachers will understand that students are expected to make use of scientific concepts and principles, identify evidence, and explain reasons to justify their claims. 3) Teachers will understand that explanation discussions are intertwined with scientific argumentation. Depending on the learning goal, sometimes it is important for students to reach a particular conclusion, but many times getting to a "right answer" is not the focus. Rather, we want students to engage in authentic scientific practice – use their conceptual understanding and argumentation skills (i.e., use evidence and reasoning to justify their claims to consider different possibilities for genuine questions). **Why** 4) Teachers will understand that explanation discussion is important because it gives students opportunities to go beyond the "correct answer" and engage in the scientific practice of sense-making and argumentation, which is the core of scientific discipline. **When** 5) Teachers will understand that explanation discussions can happen at the end of an investigation or a series of investigations, therefore, they can take place in the middle or towards the end of a unit. **How** 6) Teachers will understand that they can prompt and probe students to use evidence and scientific reasoning to justify their explanations/claims. 7) Teachers will understand that there are a variety of talk moves that they can draw on to facilitate explanation discussion. 8) Teachers will understand that it is important for students to listen to each other's arguments, and to critique and challenge the arguments in a respectful manner. 9) Teachers will understand talk moves can be used to widen, deepen, maintain, and shape sense-making space.
Performance of Understanding	Teachers will lead an explanation discussion in Simulation 4.
Ongoing assessment	Teachers will record themselves leading a science discussion on a topic of their choice in their real classroom and reflect on the recording with the researcher

Table 5.12 Design features and activities of Workshop 4

Design Features	Activity
Asynchronous task 1: what does it mean to teach science?	Interactive and guided inquiry on the nature of science and goal of science education (for details see below)
Asynchronous task 2: organise talk moves	Interactive and guided inquiry on organising talk moves into a dialogue-focused framework
Synchronous task: Recap asynchronous tasks (5min)	Recall main takeaways from tasks 1 & 2
Mini lecture (10mins)	To clarify some misunderstandings identified in the asynchronous task and introduce the analogy of leading a discussion, zooming in and zooming out
Synchronous task 3: Collective Reflection (40 mins)	In groups of 3-4, each teacher shares a 5-minute excerpt of their simulation recording and reflect on the following questions. **Zooming out - paying attention to the overall direction of the discussion:** What did the teacher do to help students to move their thinking forward? What can the teacher do differently to help students to move their thinking forward? **Zooming-in - paying attention to each moment/turn of talk?** At which moment, do you think the teacher's response to students was productive? At which moment, do you think the teacher could have responded differently?
Synchronous task 4: Simulation preparation (30mins)	Understand what explanation discussion is. Prepare for the simulation by reasoning about the arguments of the students. In groups of 3-4, split the reading and then teach each other the part you've read (Jigsaw) and answer question 1 as a group. You will then read simulation task 4 individually and think about questions 2 and 3 before sharing it with the whole group (think, talk, open-exchange). One person will volunteer to take notes for the group. 1) In what ways is explanation discussion similar and different from elicitation discussion and consolidation discussion? 2) What are the merits and weakness of each argument? 3) In what ways do you think students can improve their arguments?
Simulation Guide (supporting materials)	Teachers were provided with a simulation guide which included the learning goals, the context of the scenario, their task as well as supporting tools, such as student work with commentary that model knowledge-based reasoning, content knowledge and talk moves.

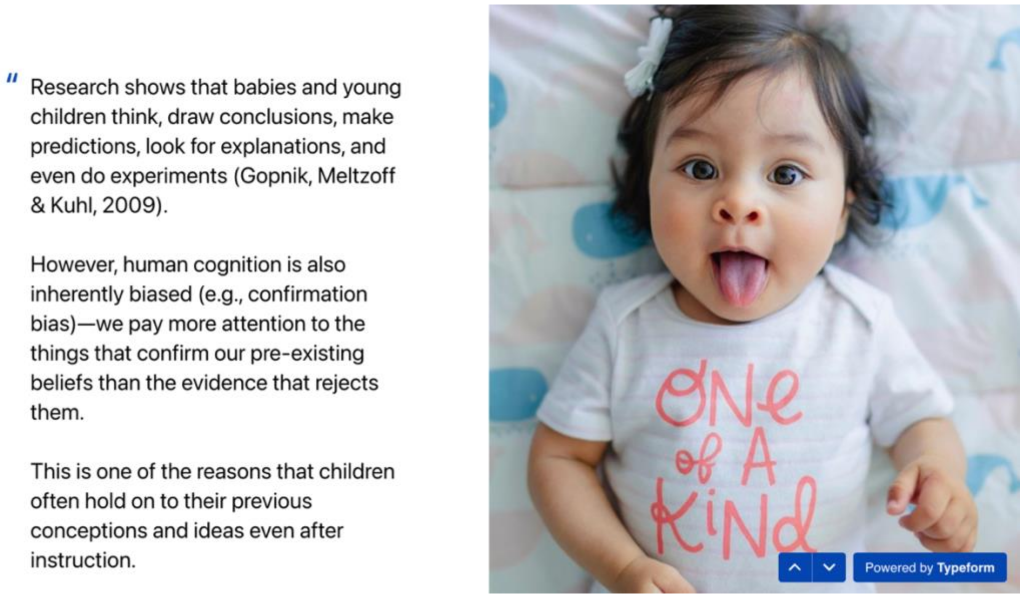
The interactive guided inquiry is an asynchronous task that teachers could complete in their own time before the workshop. The guided inquiry was designed in Typeform (https://www.typeform.com), an online survey tool, which I adapted for learning purposes. The interactive guided inquiry elicits teachers' ideas at the beginning of the inquiry (see Figure 5.37).

Figure 5.37 Elicitation of teachers' ideas at the start of the guided inquiry



The guided inquiry also provided bite-size research evidence to inform teachers' practice (see Figure 5.38).

Figure 5.38 Bite-size research evidence to inform teachers' practice

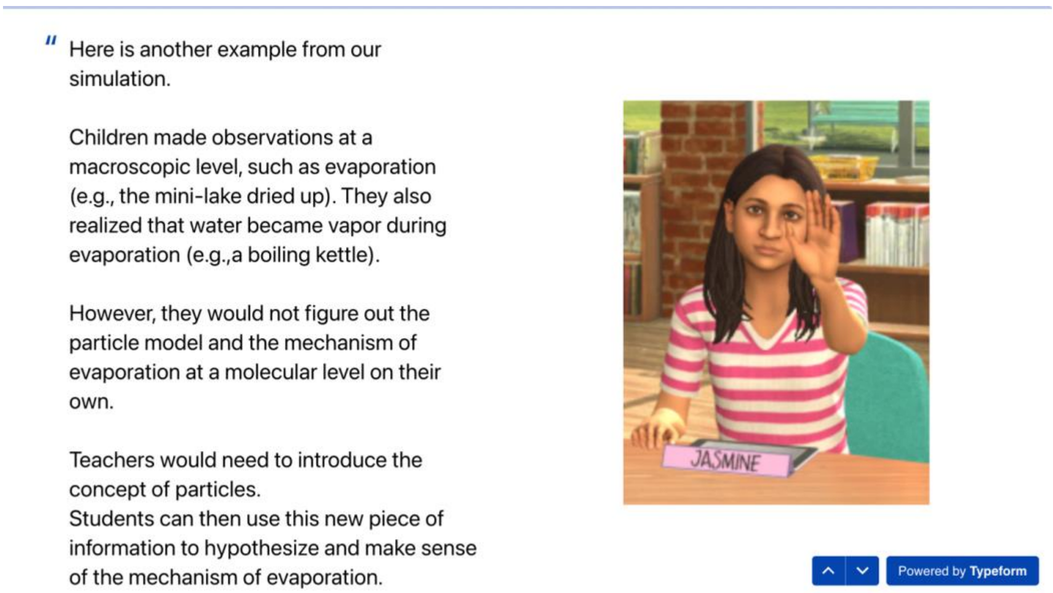


The guided asynchronous inquiry was interactive, using lucid examples to illustrate theoretical constructs, such as conceptual change in Figure 5.39.

Figure 5.39 Lucid example to illustrate conceptual change

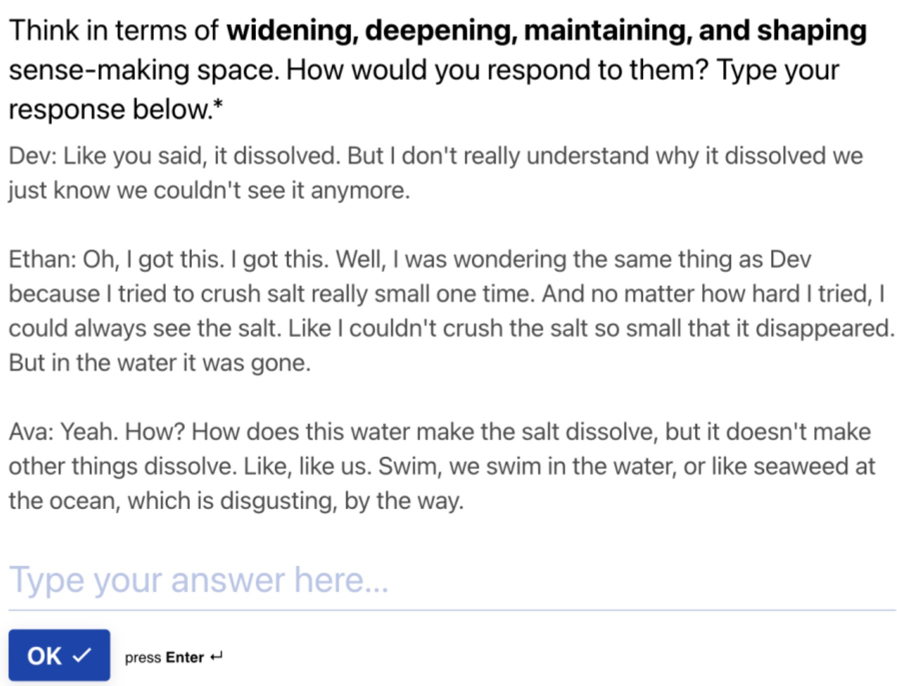
Furthermore, the guided inquiry leveraged teachers' shared experience in the simulation to develop a conceptual understanding of student sense-making (see Figure 5.40).

Figure 5.40 Leverage teachers' shared experience in the simulation during the guided inquiry



Teachers also had the opportunity to apply their learning from the guided inquiry. The scenario in Figure 5.41 drew on teachers' experience in the simulation. Here, teachers were encouraged to reconsider their responses in the simulation.

Figure 5.41 Help teachers to reconsider their responses



5.9.2 Workshop 4 implementation and feedback

The workshop took place on November 15th, 2021 and lasted for 1 hour and 30 minutes. In the same way as the last iteration, teachers were on campus during the PD. I requested teachers to use their own laptops during the PD, which allowed me to join teachers' discussions in the breakout rooms. This iteration also had a low response rate for feedback similar to Workshop 3. Seven teachers participated in the workshop and two teachers provided feedback. Teachers later told me that they had to leave the school immediately after the PD to catch their transportation. Since both Workshops 3 and 4 took place on campus, this could explain why teachers did not have the time to complete the feedback form, which was not the case in Workshop 1 and 2. In the future PD programmes, it is important to build in time for feedback instead of assuming that teachers will have the time.

Teachers' feedback was summarised below:

1) **My top 3 takeaways from this workshop.**

One teacher reflected on the importance of focusing on the larger objective of the discussion while responding to individual utterances. She also mentioned that it is not always necessary to reach a conclusion by the end of discussion, but rather focus on the quality of the discussion. The other teacher mentioned the importance of explanation discussion and how having an open discussion help to challenge our preconceived notions and lived experiences. She also mentioned maintaining a balance of scientific content and student ideas to advance student thinking.

2) Did today's workshop help you to change your way of thinking about leading science discussions? If so, use the prompt "I used to think...; I now think..." to express what has changed for you.

Teachers responded as follows:

1. I used to think that after the end of a topic the class should come to a conclusion, now I think the students should do a productive discussion about the topic regardless of thinking about the right answers at the end of the class.

2. I never realised the importance of explanation discussion but now after the workshop. I have been able to understand the need to introduce explanation discussion when the children have covered a new topic.

3) At what moment during the workshop (both asynchronous and synchronous) did you feel engaged with learning?

Both teachers reported that they feel engaged during asynchronous tasks, during the recap of asynchronous tasks, and collective reflection. Neither of the teachers mentioned the mini lecture.

4) At what moment during the workshop (both asynchronous and synchronous) did you feel least engaged with learning?

One teacher mentioned task 4 (prepare for the simulation). The other teacher reported that she felt engaged throughout the workshop.

5) Length of the workshop

Both teachers found the length of the workshop reasonable.

6) Teacher satisfaction

Both teachers felt satisfied with the workshop.

7) How do you find the asynchronous tasks? What did you like about it? What did you not like?

One teacher reported that she found the asynchronous tasks helped her preparing better for the workshop.

8) What can I do to improve the workshop today?

Two teachers responded as the following:

1. It's quite well organised and detailed
2. The workshop was very engaging, but it felt like if it was a little longer, we might have gotten even more clarity on the discussion taking place. It was very engaging and helped in clearing the misconception. I would like to appreciate that you are always very helpful and understanding and getting to learn alongside you have been a unique and unforgettable experience.

Summary of teacher feedback for Workshop 4

There was evidence of teacher learning from their reported takeaways and changes in thinking. In alignment with high level conjecture 1, teachers found guided and collaborative inquiries and collective reflections most engaging. Teachers did not find mini lectures engaging. Teachers were satisfied with the workshop and found the length of the workshop reasonable. One teacher wished the workshop could go on a little longer. Teachers appreciate the PD experience and the researcher as a facilitator.

5.9.3 Simulation 4 design

The goal of the simulation is for teachers to lead an explanation discussion that involves argumentation to advance student thinking by widening, deepening, maintaining, and shaping the sense-making space. The scenario was built upon the previous simulation to approximate a sequence of science instruction in real life. The scenario is set after a series of student experiments, consolidation discussion, and further student research. At this point, students have worked in groups to reach various explanations for the puzzle at the beginning of the inquiry, i.e., how did the ships end up in the field? Same as Simulation 3, the duration of the simulation was 15-20 minutes.

Teachers were provided with the following scenario:

Simulation scenario

After the consolidation discussion on the mini lake, you realised that children have reached a "ceiling" on their sense-making at some point, so provided additional learning opportunities for them. This is what they have done:

1) read an article on the Aral Sea

2) learned about the particle model of evaporation and condensation, and

3) how to make a scientific explanation—they understand that they need to make a claim and support it with evidence and reasoning.

This is what you instructed them to do:

You asked children to draw evidence from multiple sources from their learning experience and use reasoning to explain the causes that led up to the drying up of the Aral Sea over time. You encouraged children to look beyond the visible things and explain the process underlying the drying up of the Aral Sea. Children worked in groups or individually to make a scientific explanation about the ships in the field.

The simulation task and learning goals were the following:

Simulation task

Your task is to lead an explanation discussion. During the explanation discussion, you will:

1) Engage students in authentic science practice around using evidence and reasoning to support their claims.
2) Facilitate students to consider the merits and weaknesses of each other's explanations.
3) Use your professional judgment to decide when to open, widen, deepen, maintain, or shape the sense-making space and use the corresponding talk moves. (i.e., Zooming in to the moment).
4) Help students to move their thinking forward (i.e., Zooming out to see overall direction)

Simulation learning goals:

1) You will practice using various talk moves to open up, widen, deepen, maintain, and shape sense-making space for students.
2) You will exercise your professional judgment to decide when to open, widen, deepen, maintain, and shape sense-making space.

Graphic organiser

The same graphic organizer in the asynchronous task was included in the simulation to support observing/assistant teacher to record their observation and reflection. In this simulation, the graphic organiser specifically directed teachers' attention to moments where the lead teacher either opened, widened, deepened, maintained, shaped, or closed the sense-making space.

Table 5.13 summarises the structure and script of Simulation 4.

Table 5.13 Simulation 4 design

	Activity	Sample Script
Introduction with opportunities for recall	- Recall takeaways from the workshop - Remind teacher goals of the simulation	- Let's take a moment and recall some of what you learned in your most recent workshop with Lydia. Can you tell me what some of your takeaways were?
Preparation	- 2 minutes to prepare for the simulation	
Simulation Round 1	Elicitation discussion: ships in the field	Three scientific explanations of the ships in the field Group 1: Ava and Savannah Group 2: Dev Group 3: Jasmine and Ethan Example of student idea: Ava/Savannah: the ships in the field were stranded there because there is no more water in the Aral Sea. We learned that the field was actually a lake called the Aral Sea. The water all dried up because people took away Aral sea's water, which comes from the rivers. Argumentation points: 1. Global warming: 2. Rain and condensation 3. Simple linear causality and relational causality
Reflection (Opportunity for reflection on action immediately after the simulation)	- Elicit teacher noticing of the multifaceted class (flexible attention) - Deliberately practice talk moves	- Let's take a moment to reflect: o At which moment(s), do you think your response helped students move their thinking forward? o At which moment(s), do you think you could have responded to students differently? - Let's have our observer share her reflection. What did you record in your note catcher?
Preparation	2 minutes preparation	
Simulation Round 2	Elicitation discussion: ships in the field	Same as round 1
Reflection	- Elicit teacher noticing of the multifaceted class (flexible attention) - Elicit teachers' different perspectives of the same situation	- Welcome back. Let's briefly reflect on that second simulation. How do you feel? - At which moment(s), do you think your response helped students move their thinking forward? - At which moment(s), do you think you could have responded to students differently? - Let's have our observer share her reflection. What did you record in your note catcher?

5.9.4 Simulation 4 implementation and feedback

Seven teachers participated in the simulation, and two teachers provided anonymous feedback via google forms. The low response rate was due to the fact that this simulation session took place on a weekend. The simulation specialist was not available to conduct simulations during the weekdays, and the teachers kindly agreed to participate in the simulation session on a weekend. However, they also had other engagement, which was explains why they did not have time complete the feedback form. One of the challenges for the simulation session was in fact scheduling. Due to the time difference between Islamabad and Boston (where the simulation specialist was located), it leaves very few windows during the day where both parties are available, usually early morning in Boston and late afternoon/evening in Islamabad.

1) Cognitive load

Cognitive load was used to gauge how challenged teachers felt in the simulation to make sure the simulations were challenging enough for teachers to progress and at the same time not too challenging that they feel discouraged (High-level conjecture 3). One teacher reported a cognitive load of 3 and the other teacher reported a cognitive load of 4, which aligns with the results of the previous iterations, i.e., the range of teachers' cognitive load is usually between 3 and 4.

2) Memorable moment

One teacher said she was really happy to see Savannah (the hesitant case pupil) participate in the discussion. The other teacher said she felt she was able to conduct the discussion smoothly.

3) What is helping me to learn in this simulation?

One teacher mentioned the simulation guide, and the other teacher said getting to know different discussion types and talk moves.

4) What changes are needed in this simulation to improve learning?

One teacher said the simulation is challenging and engaging, and she did not have any suggestion. One teacher mentioned that responses of avatar students should lead towards a direction.

5) Cultural appropriateness of avatar students

One teacher agreed and the other teacher strongly agreed that the avatar students were portrayed realistically and were culturally appropriate.

6) What changes in the avatar students would you like to suggest?

Teachers did not make any suggestion.

7) The workshop prepared me sufficiently for the simulation

Both teachers agreed that the workshop prepared them sufficiently for the simulation.

8) Simulation as a reinforcement for learning

Both teachers agreed that the simulation allowed them to have a deeper understanding of the materials in the workshop.

9) Simulation time

Both teachers agreed that they had sufficient time with the avatar students for the discussion.

10) The simulation task guide

Both teachers agreed that the simulation guide provided sufficient content knowledge for them to approach the science topic. One teacher agreed and the other teacher strongly agreed that the simulation guide provided them with sufficient pedagogical knowledge.

11) What additional support would you have liked to help you prepare for this simulation experience?

Teachers did not respond to this question.

12) Other comments

Teachers did not respond to this question.

Summary of teacher feedback on Simulation 4

Even though the feedback in this iteration was limited, the results aligned with previous iterations. The difficulty level of the simulation was appropriately set—it was challenging, but not overly challenging and allowed teachers make progress. Teachers value the learning experience in the simulation and conducting discussion with various dialogic framings (i.e., elicitation, consolidation, and explanation discussion) and develop a repertoire of talk moves. Teachers found 15-20 minutes enough to conduct an explanation discussion in the simulation. Teachers found the simulation guide helpful in preparing them for the simulation. There was some difficulty with scheduling due to time zone difference.

5.9.5 Reflection as a design researcher

The guided inquiry (asynchronous task) was a design feature that emerged out of teachers' feedback and their need to shorten the duration of the synchronous workshop. In this iteration, it was observed that the interactive asynchronous task has more affordances. First of all, it reduces the cognitive load in a workshop by chunking the materials into smaller tasks that spread across time. Teachers could engage with the task at a time and location that was convenient for them. Secondly, in the spirit of a 'flipped classroom', the asynchronous tasks prepared teachers with the necessary background information to engage productively in collaborative inquiry. Thirdly, the interactive format of the asynchronous task was engaging for teachers rather than doing readings alone. The guided inquiry provided teachers the opportunity to reflect, research evidence, and opportunity to connect it to their own teaching experience. Last, but not least, the researcher/teacher educator could collect teachers' responses during the guided inquiry, and gauge teachers' understanding which informs the design of the workshop.

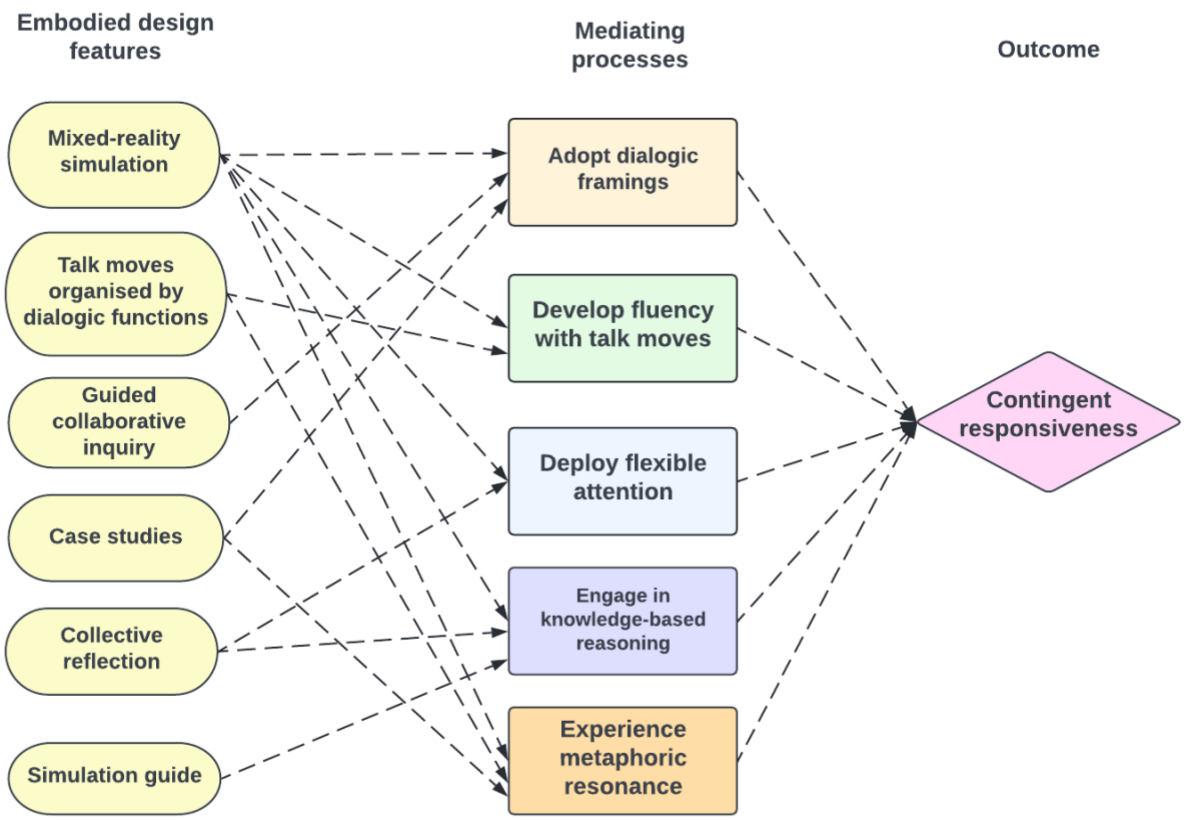
The guided inquiry (asynchronous task) was not included at the beginning of the design, rather it emerged out of necessity during the implementation. This incidence demonstrates the flexibility of DBR that allows researchers and practitioners to design and adapt as the project evolves to test new design features and conjectures. Such flexibility and agile co- design enhance the ecological validity of the design and increase the chance that the design product will function well in its intended context.

Following Hennessy et al.'s (2011) 'dialogic co-inquiry' approach to PD, this experience of co-designing a PD programme with practitioners has advanced knowledge of professional theory and practice. The equitable collaboration between university researchers and classroom practitioners has proven to very fruitful in this study. CR as a theoretical construct was not well understood at the beginning of the study. As the DBR progresses, more design features and mediating processes start to emerge out of teachers' feedback alongside my observation and continuous consultation with the literature. As a researcher and designer, I also found the whole process of co-design with practitioners in DBR highly motivating because of the immediate impact made throughout the design process.

5.9.6 Refined high-level conjectures and conjecture map

The refined high-level conjecture after four iterations is presented in Figure 5.42. The dotted line represents the hypothetical nature of the conjectures, which I examine in Chapter 7.

Figure 5.42 Conjecture map after four iterations



5.10 Summary of the chapter

This chapter presented the design, implementation, feedback, reflection, and improvement of four DBR iterations. The four iterations progressively built upon each other over time both conceptually and in terms of design.

Teachers followed a progressive learning trajectory to:

1) understand the features of dialogic discussions.

2) elicit learners' initial understanding with talk moves during elicitation discussion.

3) attend to student science ideas, lived experience, and classroom equity.

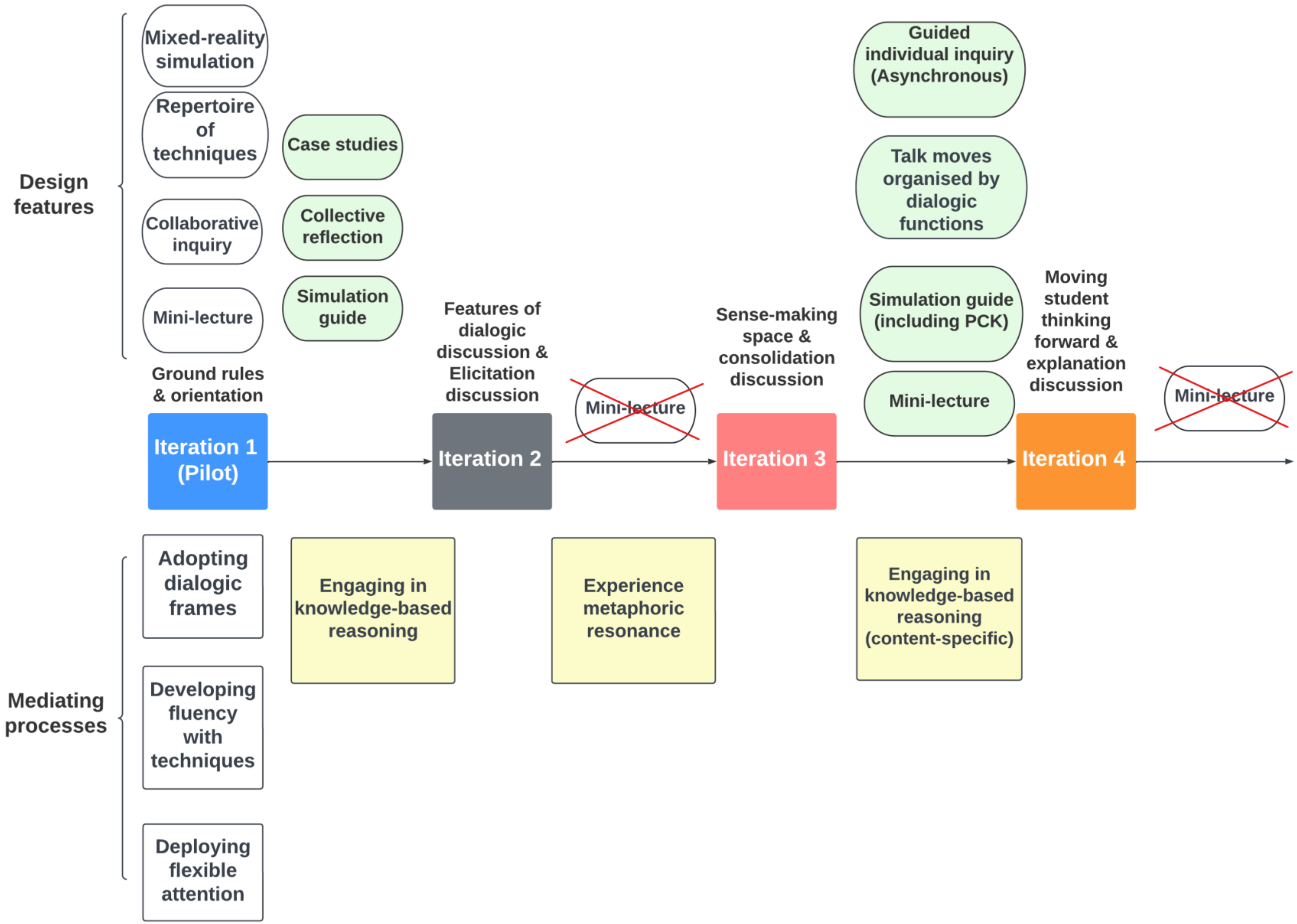
4) conceptualise discussion as a sense-making space, in which they could widen, deepen, maintain, and shape.

5) unpack hands-on activities during consolidation discussion.

6) engage students in the authentic epistemic practice of the discipline, such as scientific argumentation. 7) interpret the disciplinary substance of student ideas and support students to move their thinking forward.

The design was also improved across four iterations. For example, the simulation guide was introduced after iteration 1 and was improved over four iterations. New design features were added, such as case studies and asynchronous guided inquiry, whereas others were removed and reintroduced for testing, such as the mini lecture. In addition to the three mediating processes identified in Phase 1 (e.g., adopt dialogic framings, deploy flexible attention, and develop fluency with a repertoire of techniques), new mediating processes emerged during the iterations, such as engaging in knowledge-based reasoning and experiencing metamorphic resonance. Figure 5.43 provides an overview of the refinement process across four DBR iterations. The white circles and white rectangular boxes represent the initial design features and mediating processes identified in Phase 1. Added design features and mediating processes were highlighted in green and yellow, respectively. The red cross indicates the removal of a design feature. The next chapter presents findings on the effectiveness of the PD.

Figure 5.43 Overview of the refinement process across four DBR iterations



Chapter 6 Did the PD work? Analysis and results for RQ1

In this chapter, I present analysis and results to answer Research question 1, which seeks to evaluate the effectiveness of the PD by comparing teachers' CR before and after the PD.

RQ1: To what extent were teachers contingently responsive to students during science discussions before and after the PD?

6.1 Data sources

Due to the pandemic, the school experienced a very high attrition rate in 2021. Seven out of the thirteen teachers who participated in the first iteration left the school at the end of the first academic year (after Iteration 2) and one teacher left after the first semester of the second academic year (after Workshop 4). Three new teachers came on board at Iteration 3. Among the five remaining teachers who joined the study from the very beginning, one teacher from the kindergarten level withdrew from the study after Iteration 2 due to some reshuffling of the staff at the administrative level. Amongst the four teachers who participated in all four iterations, three teachers from Grade 1-3 (Fatima, Minahil, and Amna) provided both pre- and post-PD video recordings of their classroom discussions. The fourth teacher Zainab (Grade 6-8) did not provide her post-PD video recording after two reminders. I heard from the other teachers that Zainab's grade level was facing some challenges, so I did not press her further. As a result, data from Fatima, Minahil, and Amna were included for the analysis to evaluate the effectiveness of the PD by comparing teachers' pre- and post-PD response patterns.

All three teachers were new to teaching and to the school. The three teachers were co-teaching the project classes for grades 1-3 (which include science subjects). Teachers were asked to record their science classroom discussion for approximately 20 minutes both before and after the PD. There was no specific framing or topic given to teachers, who had the freedom to interpret what a science discussion is, where it is situated in a sequence of instructions, how they wanted to lead the discussion, as well as the topic of the discussion. The open-ended nature of the task allowed me to assess both changes in teachers' responsiveness and to gauge their conceptual understanding of science discussion. To measure the extent to which teachers were contingently responsive to students before and after the PD, the three teachers' pre- and post- PD classroom discussion recordings were transcribed, systematically coded, and analysed using epistemic network analysis (ENA).

6.2 Methods of analysis

A combination of systematic coding and epistemic network analysis (ENA) was used to compare teachers' response patterns before and after the PD both visually and statistically (Shaffer et al., 2016). The coding scheme was conceptualised based on Wegerif's (2010) notion of dialogic space. The coding scheme was developed in consultation with my supervisors and another doctoral student at the Faculty of Education, University of Cambridge. The initial conception and draft of the coding scheme were approved by my supervisors, which was then refined across three iterations. In each iteration, the doctoral student and I coded a sample of the data, after which we talked about the discrepancies, addressed any conceptual issues, refined the codes, and sharpened the definitions.

In the coding scheme, a class discussion was conceptualised as a dialogic space, and teachers' responses were coded based on their dialogic function, i.e., widening, deepening, maintaining, and shaping the dialogic space. "Initiating" and "feedback" were also included as part of the coding scheme. Though initiating and feedback are often associated with a monologic discourse controlled by teachers, research has shown that they could carry dialogic functions (e.g., Boyd & Markarian, 2011). Furthermore, science discussion is often made up of a combination of monologic and dialogic discourse in service of students' sense-making (Mortimer & Scott, 2003). Therefore, the coding is based on the dialogic function it fulfils rather than the form of talk (for the full coding scheme, see Appendix 2).

All three teachers' recordings of pre- and post-PD discussions were systematically coded using the dialogic function coding scheme. 10% of the dataset was randomly selected and coded by the doctoral student and I independently. Three rounds of coding were conducted in total. In the first round, we each coded one-third of the full transcript of one teacher's discussion, and we clarified the definition of 'initiate' and resolved any discrepancies. We then continued to code another one-third of the transcript and compared our coding, during which we found that we had achieved reasonable inter-rater reliability for most of the codes except for 'deepen'. We then met to discuss and refine the specific code before coding the rest of the transcript. The inter-rater reliability using Cohen's kappa (Cohen, 1960) is calculated below using SPSS version 28.0.1.1 shown in Table 6.1:

Table 6.1 Cohen's kappa for each code in the dialogic function coding scheme

Codes	Cohen's kappa
Initiate	0.642
Feedback	0.751
Widen	0.784
Deepen	0.612
Maintain	0.895
Shape	0.721

According to Cohen (1960), values between 0.61–0.80 are considered substantial agreement, and 0.81–0.99 are considered near-perfect agreement. The results indicate substantial agreements for the codes, initiate, feedback, widen, deepen, and shape, and near-perfect agreement for the code maintain.

After the systematic coding, epistemic network analysis (ENA) was used to create visualisations of teachers' discourse patterns and to statistically test whether there was any difference before and after the PD. ENA is a quantitative ethnographic method for quantifying, visualising, and interpreting the structure of connection in data (Shaffer et al., 2016). In other words, ENA identifies connections among codes in a dataset, measures the strengths of their connections, and visualises them in a network. ENA was initially developed to model cognitive networks, the patterns of association between knowledge, skills, values, and habits of mind which characterise complex thinking (Shaffer, 2006). ENA has been used to model patterns of association in a variety of systems and fields of studies, such as modelling discourse and scientific practice during collaborative game (Bressler et al., 2019), uncovering the relationship between social and cognitive presence in communities of inquiry (Rolim et al., 2019), modelling how surgeons with different levels of experiences use procedural simulations (Ruis et al., 2019), and social gaze coordination (Andrist et al., 2015).

ENA models the connections between codes by quantifying the co-occurrence of codes within conversations, producing a weighted network of co-occurrences. ENA analyses all of the networks simultaneously, resulting in a set of networks that can be compared both visually and statistically (Shaffer et al., 2016). In the case of this study, in addition to the visual comparison between the teachers' response network pre- and post-PD, a two-sample t-test was run on the networks to detect changes and effect size pre- and post-PD.

To conduct ENA, I used the ENA Web Tool (version 1.7.0)(Marquart et al., 2018). I defined the units of analysis as all lines of data associated with a single value of the discussion subsetted by the teacher and turn number. For example, one unit consisted of all the lines associated with teacher Minahil and turn number 1. The ENA algorithm uses a moving window to construct a network model for each line in the data, showing how codes in the current line are connected to codes that occur within the recent temporal context (Siebert-Evenstone et al., 2017), defined as 5 lines (each line plus the 4 previous lines) within a given conversation. The size of the overlapping window was determined by experimenting with various window sizes and examing whether the connections among codes are reflected in the qualitative data. The resulting networks are aggregated for all lines for each unit of analysis in the model. In this model, I aggregated networks using a binary summation in which the networks for a given line reflect the presence or absence of the co-occurrence of each pair of codes. The ENA model included the following codes: Initiate, Feeback Widen, Deepen, Maintain and Shape. I defined conversation as all lines of data associated with a single value of a discussion. For example, one conversation consisted of all the lines associated with Minahil's pre-PD discussion.

The ENA model normalised the networks for all units of analysis before they were subjected to a dimensional reduction, which accounts for the fact that different units of analysis may have a different number of lines (See Shaffer et al., 2016 for a more detailed explanation of the mathematics). Networks were visualised using network graphs where nodes correspond to the codes, and edges reflect the relative frequency of co-occurrence, or connection, between two codes. ENA produced two coordinated representations for each unit of analysis: (1) a plotted point, which represents the location of that unit's network in the low-dimensional projected space, and (2) a weighted network graph. The positions of the network are determined by an optimisation routine that minimises the difference between the plotted points and their corresponding network centroids. Because of the co-registration of network graphs and projected space, the positions of the network graph nodes and the connection between the nodes can be used to interpret the dimensions of the projected space and explain the positions of plotted points in the space. The model of this analysis had co-registration correlations of 0.92 (Pearson) and 0.91 (Spearman) for the first dimension and co-registration correlations of 0.74 (Pearson) and 0.74 (Spearman) for the second. In summary, ENA allows comparison between teachers' pre- and post-PD response patterns both visually and statistically in terms of their plotted point positions, individual networks, mean plotted point positions, and mean networks, which average the connection weights across individual networks.

It is important to note that dialogic functions do not necessarily indicate the quality of the talk. For instance, the connection widen-maintain could indicate a 'popcorn' type of discussion, where students take turns to share ideas without building on and challenging each other's contributions. Widen-maintain could also mean a teacher maintains the dialogic space by taking up a student's question/idea and widening it by encouraging other students to build on the idea. Therefore, it is crucial to return to the original data to make sense of the response pattern, which Shaffer (2017) called 'closing the interpretive loop'.

6.3 Results

Each teacher's response pattern before and after the PD was presented, followed by short excerpts from the data to make sense of the response patterns and to close the interpretive loop.

6.3.1 Fatima's pre- and post-PD response pattern

Fatima was a first-year teacher. Her pre- and post-PD discussion took place in the same first-grade project class. The pre-PD discussion was an online discussion on zoom, and the post-PD discussion was face to face. As shown in Figure 6.1 and Figure 6.2, Fatima's response pattern appears visually very different before and after the PD. Fatima's response pattern pre-PD discussion focused on initiate-feedback (M=0.36), and her post -PD response showed the strongest connections between maintain-widen (M=0.25) and maintain -initiate (M=0.22).

The visual differences between Fatima's pre- and post-PD response patterns are also confirmed by statistical tests. Along the x-axis, a two-sample t-test assuming unequal variance showed Fatima's pre-PD discussion (mean=-0.33, SD=0.43, N=70) was **statistically significantly different** at the alpha=0.05 level from Fatima's post-PD discussion (mean=0.02, SD=0.51, N=38; t(65.16)= -3.61, p=0.00, Cohen's d=0.77). Along the y-axis, a two-sample t-test assuming unequal variance showed Fatima's pre-PD disucssion (mean=-0.23, SD=0.40, N=70 **was statistically significantly different** at the alpha=0.05 level from Fatima's post-PD discussion (mean=0.06, SD=0.41, N=38; t(74.05)= -3.45, p=0.00, Cohen's d=0.70).

Figure 6.1 Fatima's pre-PD response pattern

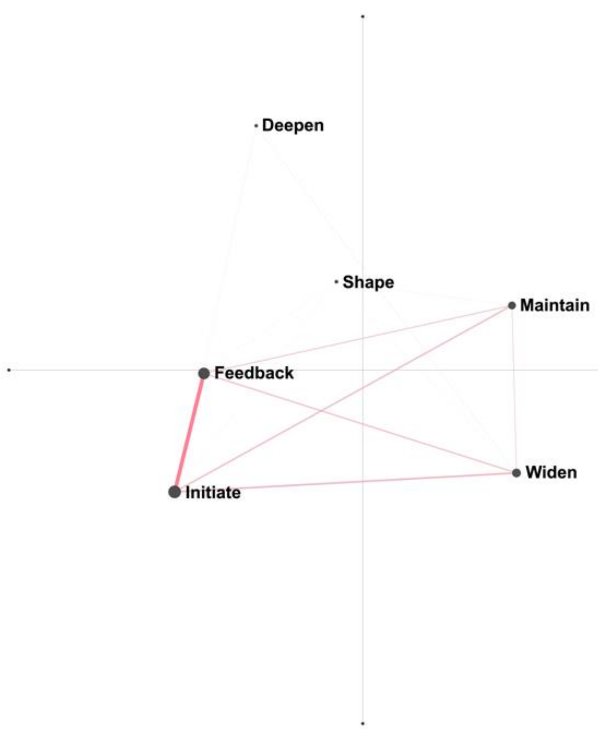
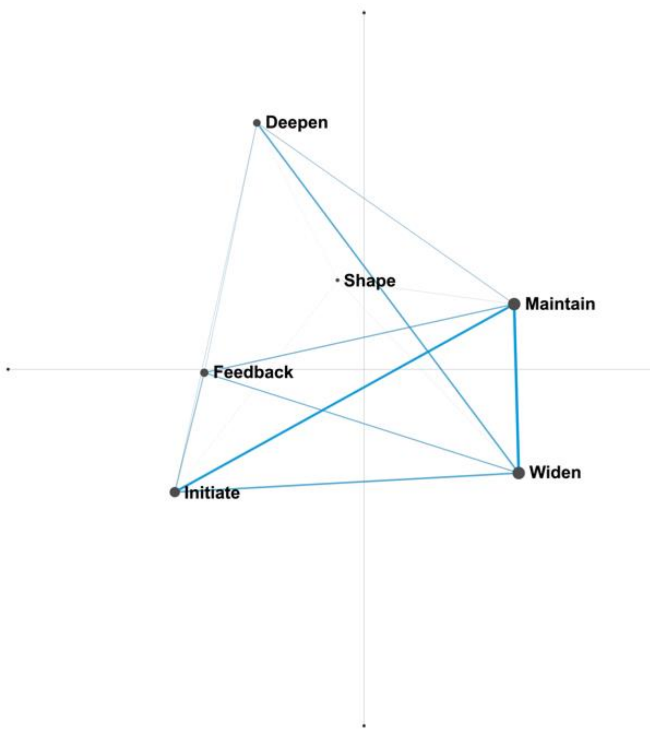


Figure 6.2 Fatima's post-PD response pattern



6.3.1.1 Fatima's pre-PD response pattern

Before the PD, Fatima's classroom discussion was primarily characterised by IRE/IRF type of discourse, which was evident in her response pattern, with the strongest connection between initiate and feedback (M=0.36).

Triangulating with the researcher's observation, the pre-PD discussion fell under the authoritative and interactive dimensions of Mortimer and Scott's (2003) communicative approach, where the teacher was in control of the flow of the talk, initiated questions, and provided feedback. Fatima's pre-PD discussion could be divided into three parts. The first part of the discussion consisted of Fatima reading a story about the five senses of humans to students while pausing after every page to interact with the students. In the second part of the discussion, the students experienced their five senses by observing, hearing, smelling, and tasting a fruit, during which Fatima called upon individual students to talk about their fruit. The short excerpt in Table 6.2 illustrates the IRE/IRF pattern during the discussion. The third part consisted of a short lecture, where Fatima explained the assignment about five senses to students.

Table 6.2 Excerpt of Fatima's pre-PD discussion

Turn	Speaker	Utterance
96	Fatima	It's juicy. Is it crunchy? Is it sour or sweet? All of your apples are sweet and juicy. Is anyone's sour?
97	Unidentifiable student	Mine is sour.
98	Fatima	Oh, yours is not sweet. Okay, how is your peach, Ibrahim? What does it taste like?
99	Ibrahim	My peach is yummy for your tummy.
100	Fatima	But is it sweet or sour? Or juicy?
101	Ibrahim	It's rough in the centre. Juicy.
102	Fatima	It's juicy. Okay, so can you hear any sound from the Apple if you bring it close to your ear?
103	Ayesha	Yes.

6.3.1.2 Fatima's post-PD response pattern

For the post-PD discussion, Fatima chose to frame her discussion as a consolidation discussion, which is often used after an investigation/hands-on activity to consolidate students' conceptual understanding. Fatima's consolidation discussion took place after a field trip, during which students visited a local lake and observed the pollution in the lake. Fatima's post -PD response showed the strongest connections between maintain-widen (M=0.25) and maintain-initiate (M=0.22). This response pattern aligns with her framing of consolidation discussion, requiring teachers to achieve a balance between authoritative discourse (keeping the discussion focused by initiating a series of questions to help students connect their experience to targeted scientific concepts) and dialogic discourse (eliciting a variety of student experiences and following student ideas). Triangulating with the qualitative data, the pattern reflected in ENA matched the researcher's observation.

Fatima's post-PD discussion revolved around connecting children's observations during their field trip to the larger topic of the environment that they were studying. The instructional goal was to consolidate children's understanding about pollution, recycling, reducing and reusing by helping students to make connections to their observations during the field trip. She opened the discussion by having children recall what the environment is. During this process, two children diverged the discussion by talking about the importance of taking care of the environment. Fatima first maintained the dialogic space by revoicing these ideas to the whole class and deepening the dialogic space by prompting students to come up with solutions to address the problems. She was mindful to give equitable opportunities for children to participate and regularly circled back to the question about children's observations to elicit more student ideas. Therefore, the discussion alternated between talking about "what do you see during the field trip" and "what should we do?". It was also noticed that one student had the tendency to dominate the class discussion and spoke about his ideas that were not necessarily relevant to the field trip. Fatima wrestled to achieve a balance of being caring to the students and keeping a coherent line of discussion for the class. As a result, she would follow up on the student's ideas and attempt to make connections between the student's ideas (though many of them were not about the field trip) and her instructional goal.

The excerpt in Table 6.3 illustrates how Fatima was caring and respectful towards Ibrahim's ideas (though they are not directly connected to the field trip) by revoicing and maintaining the dialogic space, and then widening the discussion by having Mahnoor and Maha share their observations.

Table 6.3 Excerpt of Fatima's post-PD discussion

15	Fatima	…What happened on the trip? What did you guys see on the trip?
16	Unidentifiable student	Lot of junk.
17	Fatima	Who threw the junk?
18	Students	People!
19	Fatima	People. What... [interrupted by Ibrahim]
20	Ibrahim	The animals who eat them will die, and we cut trees and the grass. It is like a cycle, if we start moving the grass so much, the animals who eat grass will die, and the animals who eat them will die. And if we start cutting trees the birds won't have places to make nests.
21	Fatima	What should we do Ibrahim?
22	Ibrahim	We should stop cutting trees, and... we should...hmmm...save animals. and hunting, like snow leopard
23	Fatima	Exactly. Ibrahim said we should stop cutting trees and hunting. So, yes Mahnoor. Are you going to mention what you remember about the trip? Yes?
24	Mahnoor	How about we use...we can write...in the backside of the paper.
25	Fatima	Yes. So, another thing that Mahnoor had suggested and Ibrahim suggested was that we should stop cutting trees [Ibrahim injected] ("and stop hunting"). Mahnoor said in order to save paper, we should use the backside of the paper as well. That way you will be reducing the amount of waste paper waste that we make Yes. Maha?

6.3.2 Minahil's pre- and post-PD response pattern

Minahil was a first-year teacher. The pre- and post-PD discussion took place in two different first-grade project classes in zoom and on campus respectively. As shown in Figure 6.3 and Figure 6.4, Minahil's response patterns appears visually very different both before and after the PD. Minahil's pre-PD response focused on initiate and feedback (M=0.23), and her post -PD response showed the strongest connections between maintain and widen (M=0.46).

The visual differences between Minahil's pre- and post-PD response patterns were also confirmed by statistical tests. Along the x-axis, a two-sample t-test assuming unequal variance showed Minahil's pre-PD discussion (mean=-0.24, SD=0.34, N=51 was **statistically significantly different** at the alpha=0.05 level from Minahil's post- PD discussion (mean=0.37, SD=0.49, N=38; t(62.26)= -6.63, p=0.00, Cohen's d=1.50). Along the y-axis, a two-sample t-test assuming unequal variance showed that Minahil's pre-PD discussion (mean=-0.10, SD=0.36, N=51 was **statistically significantly different** at the alpha=0.05 level from Minahil's Post-PD discussion (mean=0.08, SD=0.36, N=38; t(79.80)= -2.30, p=0.02, Cohen's d=0.49).

Figure 6.3 Minahil's pre-PD response

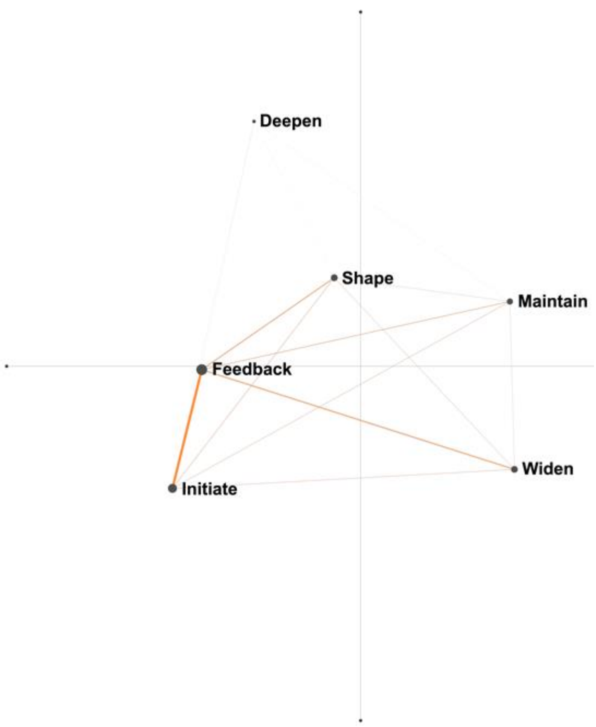
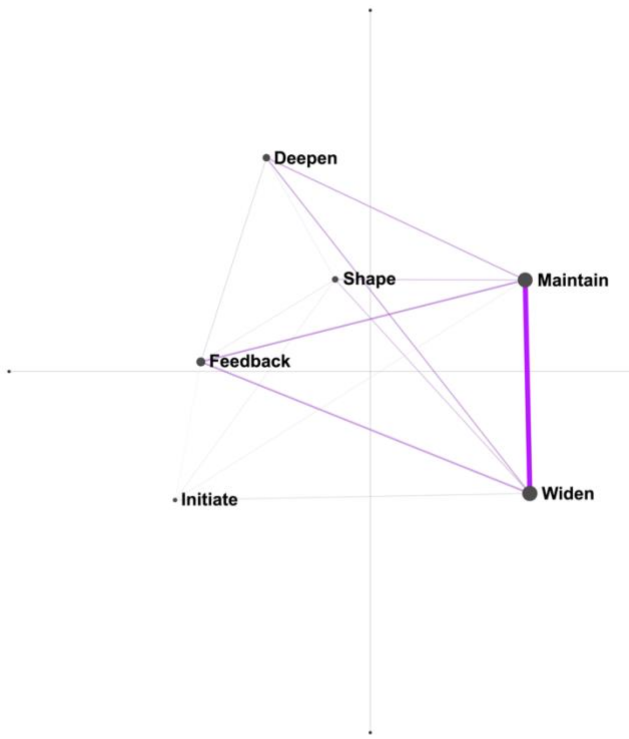


Figure 6.4 Minahil's post-PD response



6.3.2.1 Minahil's pre-PD response pattern

Before the PD, Minahil's classroom discourse was primarily characterised by IRE/IRF, which was evident in her response pattern, with the strongest connection being between initiate and feedback (M=0.23). There was also a relatively strong connection between widen and feedback (M=0.13), i.e., Minahil would elicit a number of students' ideas before providing her feedback. This pattern is triangulated with the researcher's observation described below.

Minahil's pre-PD discussion fell under the authoritative and interactive dimensions of Mortimer and Scott's (2003) communicative approach. Minahil was delivering a lecture while interacting with students. She first started the discussion by having students recall their learning from previous lessons. During the lecture, she often started a new slide with questions and asked multiple students to answer them before providing her feedback and going over the content on the slide. She also paused frequently to check on students' understanding through interactions with the IRE/IRF pattern of discourse.

The excerpt in Table 6.4 shows how Minahil started a new slide with an open-ended question, invited two students to answer, and then provided her feedback. During the discussion, she also invited children to ask questions on multiple occasions. She tended to answer the questions rather than seeing this as an opportunity to open the dialogic space for collective sense-making.

Table 6.4 Excerpt of Minahil's pre-PD discussion

Turn	Speaker	Speech
17	Minahil	All right. Okay. So now we are going to talk about metamorphic rocks. That is the third type of rock that we want to study. Okay, so metamorphic rocks are made from other rocks that have changed form. These rocks can be igneous, sedimentary, or even old metamorphic rocks. So guys, how are metamorphic rocks formed? They are formed by all three types of rocks they can be igneous, sedimentary, or old metamorphic rocks. Isn't that strange? This is very interesting that metamorphic rocks are a combination of all three different types of rocks. How do you think these rocks come together to form metamorphic rock? How is this possible?
18	Unidentifiable student	Because it says morph
19	Students	[Students speaking all at the same time]
20	Minahil	Ok one by one. I can't hear anyone. Saim is going to tell me.
21	Saim	Millions thousands of years. When thousands of years pass, metamorphic rocks, sedimentary, turns into a big big metamorphic rock. that's very heavy.
22	Minahil	Guys Saim is saying that when billions of years pass all the rocks turn into metamorphic rock. Does anyone else want to add something to it?
23	Ayesha	Ma'am. I want to tell you how metamorphic rocks are made. I got disconnected, so I didn't hear anything. I mean rocks can become metamorphic rocks like this if sedimentary rocks come out of a wave in into a place where there is a rocky place where there is a lot of heat and pressure when sedimentary rocks can be pulled out of the wave into that area. And that means that there are thousands of years and can become metamorphic and igneous. Igneous just comes out and if like that if there is a place when heat and pressure if metamorphic rocks come out in that place, it means that it they can even they can be made more they can be made after more than 1000 years.
24	Minahil	Yeah, actually Ayesha you're right so actually right that all these rocks when they get together, and they combined together and when there is a lot of heat and pressure they form a metamorphic rock that you are right actually. So let's go on to the next slide and see what it says. So most metamorphic rocks on deep underground where metamorphic rocks are formed under the ground.

6.3.2.2 Minahil's post-PD response pattern

For the post-PD discussion, Minahil also chose to frame her discussion as a consolidation discussion, which is often used after an investigation/hands-on activity to consolidate students' conceptual understanding. Like her co-teacher Fatima, Minahil's consolidation discussion took place after a field trip, during which students visited a local lake and observed the pollution in the lake. Minahil's post -PD response showed the strongest connections between maintain-widen (M=0.46), and relatively strong connections between maintain-feedback (0.17)).

The short excerpt in Table 6.5 shows how Minahil maintained and widened the dialogic space. After eliciting students' observations about the trash in the lake, Minahil pressed students to consider why people throw trash. One of the students, Maham, said it is because people do not have an education. In the retrospective interview, Minahil explained her initial surprise with Maham's answer and her decision to maintain the dialogic space by following up and revoicing Maham's contribution and then widened it by asking Faria about her thoughts on Maham's idea.

Table 6.5 Excerpt of Minahil's post-PD discussion

Turn	Speaker	Utterance
40	Minahil	Yes. So one of the reasons that people are throwing this trash is that they don't have education. hmm, Maham can you explain this a little further. What do you mean when people don't have education, [which makes them] throw trash on the ground?
41	Maham	I mean, like... [inaudible] does not have education. When that happens, if you do not know what you have to do. That' why.
42	Minahil	Okay. So I asked you all why are people throwing trash on the grounds. So Maham is saying that those people do not have education. What do you think, Faria? Is it something related to education like people throw the garbage on the floor and here and there is that does this have something related to education when people are not educated?
43	Faria	I don't know what education means.
44	Minahil	Okay, like when they do not go to school. Does anyone want to add something to it? Okay, I'll rephrase my question.

Triangulating with Minahil's retrospective interview, the strong connection between widening and maintaining is also reflected in her intention to focus on students' contributions. Compared to Fatima's consolidation discussion, Minahil focused more on widening the dialogic space by following up with student ideas. She explained:

> I was focusing on their answer, and I was trying to actually, you know, I was aware of where I can improve the sense-making space and widen it. I was consciously aware, and I was listening to their answers very carefully so that I can, you know, so that I can just like when she said that,

you know, it's they don't have education. So I was conscious at that time that I should widen the sense-making space rather than shut it down.

6.3.3 Amna's pre- and post-PD response pattern

Amna was a first-year teacher. She co-taught Grade 1-3 project classes with Fatima and Minahil. Her pre-PD discussion was an online discussion on zoom with a Grade 1 class, and her post-PD discussion was face to face in a combined lesson of two Grade 1 classes. ENA showed that Amna's response pattern appeared visually very different before and after the PD.

As shown in Figure 6.5 and Figure 6.6, before the PD, Amna's response pattern is concentrated between widen and maintain (M=0.13) whereas her post-PD response pattern is focused on deepen and maintain (M=0.18). The visual differences between Amna's pre- and post-PD response patterns are also confirmed by statistical tests.

Along the x-axis, a two-sample t-test assuming unequal variance showed Amna's Pre-PD discussion (mean=0.03, SD=0.42, N=106 was **not statistically significantly different** at the alpha=0.05 level from Amna's Post-PD discussion (mean=-0.06, SD=0.38, N=69; t (156.70)= 1.39, p=0.17, Cohen's d=0.21). Along the y-axis, a two-sample t-test assuming unequal variance showed Amna's pre- PD discussion (mean=0.02, SD=0.31, N=106 was **statistically significantly different** at the alpha=0.05 level from Amna's Post-PD discussion (mean=0.15, SD=0.36, N=69; t (127.12)= -2.59, p=0.01, Cohen's d=0.42).

Figure 6.5 Amna's pre-PD response pattern

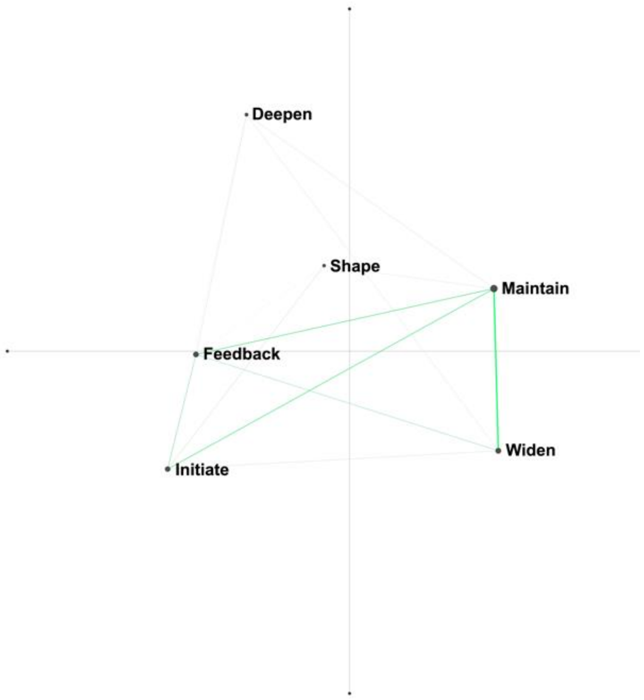
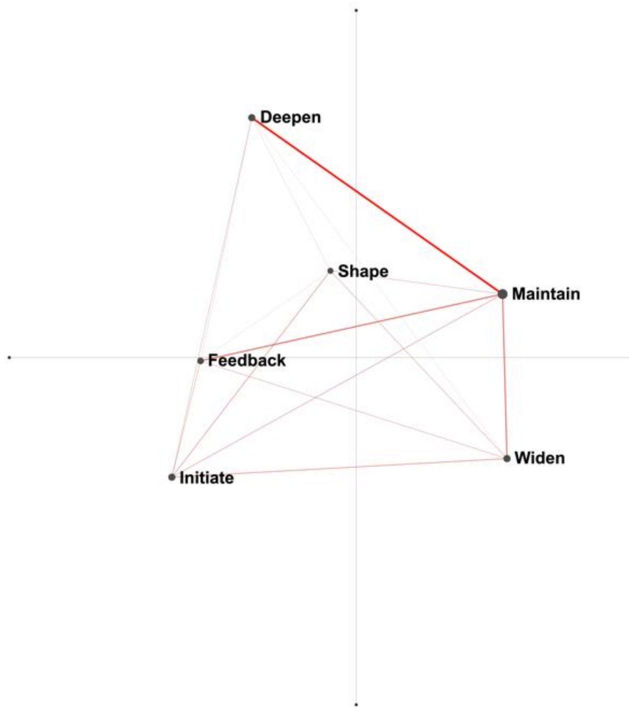


Figure 6.6 Amna's post-PD response pattern



6.3.3.1 Amna's pre-PD response pattern

In the pre-PD discussion, Amna's response pattern focused on widening and maintaining (M=0.13) the discussion. This pattern is triangulated with the researcher's observation. Amna's pre-PD discussion happened online after students had learned about rocks with Minahil. According to Amna, her job focused more on the hands-on part of the project class, and her co-teachers Minahil and Fatima focused more on the theory. Amna's pre-PD discussion revolved around the topic of making a mosaic. The purpose of the discussion was for students to come up with ideas about what mosaic they can build followed by a short lecture on the steps of making a mosaic. Therefore, Amna's pre-PD discussion was characterised by a mix of teacher-led discussion and a lecture, which fell under the authoritative-interactive dimension, and the authoritative non-interactive dimension of Mortimer and Scott's communicative approach (2003). During the discussion, Amna asked students to think of a really fun day that they had based on which they could subsequently make a mosaic. She focused on widening and maintaining discussion by taking turns to call upon various students to talk about a fun day that they had. The discussion could be characterised as a 'popcorn' discussion, where students take turns to express their ideas without connecting and building on each other's ideas. The excerpt in Table 6.6 shows Amna maintained the discussion with Hamza about making a mosaic out of his birthday gift despite being interrupted by another student for a number of turns of talk. She then widened the discussion by calling upon Ali to brainstorm some ideas about the mosaic that he would like to create.

Table 6.6 Excerpt of Amna's pre-PD discussion

Turn	Speaker	Utterance
85	Amna	Okay, Hamza, what can you remember from your birthday? Like, what was your favourite part?
87	Hamza	My gifts.
88-96	Discussion interrupted by another student	
96	Amna	Hamza, maybe you can make a mosaic out of your gifts. Maybe you can remember what your favourite gift was. And then you can make a mosaic of that. And then you can always remember it.
97	Hamza	When I got my ps4.
98	Amna	Oh, ps4. I think that will be a very interesting mosaic. Would you like to try making a ps4 mosaic?
99	Hamza	Yes.
100	Amna	I think that I think that's going to be a really fun project then. You know, so then we can figure out how to make a ps4 mosaic then we will try to draw out the shape. And then we'll sort of find the paper and different material that looks like the ps4. What do you think? Yeah. All right. Ali, can you think of a really happy fun day?

6.3.3.2 Amna's post-PD response pattern

In the post-PD discussion, Amna's response pattern focused on deepening and maintaining (M=0.18) the discussion. This pattern is triangulated with the researcher's observation and her retrospective interview. According to Amna, this discussion happened at the beginning of a project about sound. It is important to note that the video shared by Amna took place in a combined class (i.e., two classes of students were combined into one due to a low attendance rate). However, most of the students ended up coming to school later, which is why her class appeared crowded and had twice as many of learners as a normal class. Before this discussion, the class has done one lesson about sound.

Amna started the discussion by asking students to recall where sound comes from and tried to illustrate it by using the example of a phone vibrating. Then she broke the class into different small groups and brought a guitar to each small group to demonstrate the relationship between vibration and sound. During the demonstration of the first group, students wanted to check the sound of different strings, and Amna took up the students' inquiry. As students heard different strings, they noticed the thickness of the string influences the sound it makes. Amna maintained the dialogic space by taking up students' observations and deepened the dialogic space by asking students to question the relationship between volume, pitch, and the speed of vibration. She further maintained the dialogic space by framing students' inquiries into a question before going to the next group. The excerpt in Table 6.7 illustrates how Amna maintained the dialogic space in this first group by taking up students' ideas and deepened it by challenging their assumptions about volume.

Table 6.7 Excerpt of Amna's post-PD discussion with Group 1

48	Amna	Okay, thank you. So see this is one way that we can see the strings vibrate.
49	Abudullah	I want to check these two.
50	Amna	Okay, my Anya, can you check these two for Abdullah as well?
51	James	This one is louder.
52	Amna	Is it louder?
53	Sadaf	And this is the first A key string.
54	Amna	Is it louder or does it sound deeper?
55	Sadaf	It is deeper.
56	Unidentifiable student	it is louder because...it's...
57	Amna	The volume level is the same, but the sound is sharp and it's loud.
58	Maria	inaudible...this one is a little faster...louder one.
59	Abudullah	Ahhhhh! I can see it! This one is very very thin, it isa bit faster.
60	Amna	Okay, thank you. All right, let's go show it to the other group now. No. All right, those are very good observations. So I want you guys...I want you to give me a reason, talk to each other about the volume and speed...trying to figure out why is it different string makes a different sound.

The excerpt in Table 6.8 illustrates how Amna again maintained and deepened the dialogic space with the students in the second group. During the demonstration, students noticed that there was a hole in the middle of the guitar. Amna maintained the dialogic space by taking up the student's question. Amna first elicited one student Sadaf's idea and then maintained the dialogic space by covering the sound hole and having students listen to the differences to come up with different hypotheses. The episode lasted 25 turns involving six students. Before leaving the group, she maintained the dialogic space by signalling to students about the ongoing nature of the dialogic space that they will return to this puzzle and come up with an explanation. It is noticeable that students often talked over each other during the discussion. Amna was aware of it and noted in the retrospective interview that she wanted to improve on her classroom management and cultivate a culture of productive talk in her class.

Table 6.8 Excerpt of Amna's post-PD discussion with Group 2

81	Rimsha	Why is there a big circle?
82	Amna	Why is there a big circle? That's a very good question.
83	Multiple students	inaudible
84	Sadaf	I can talk.
85	Amna	Let Sadaf answer the question.
86	Sadaf	It is a sound hole. But when I do this, it goes in this and comes back when I do this I do it more deeper. it goes in and comes out more deeper.
87	Amna	So what happens yes, thank you. That's pretty good. So what happens is that if this hole...or can I have a piece of paper or can I have a piece of that cardboard?
88	Amna	[Amna covered the sound hole with a piece of cardboard]. Let's keep this here for a second. Can you pull this thing now? You can hear the sound right now and listen for the difference and tell me if you can hear it.
89	Amna	Can you do it now? .
90	Sadaf	See?
91	Amna	So what's the difference?
92	Hafsa	The vibration, the vibration! Ma'am. When the hole is, the vibration gets more. when the hole isn't, the vibration gets less.
93	Amna	Okay, just listen once more and very quietly listen to the difference. We'll pull the same string again and focus on this one. (Sadaf pulled the string) Yeah, that's right. That's one sound. Now listen again. [Amna removed the cardboard from the sound hole. Sadaf pulled a string]
94	Unidentifiable student	This is louder.
95	Multiple students	Multiple students all speaking at the same time to each other.
96	Sadaf	Inaudible
97	Ibrahim	And it bounces back!
98	Sadaf	Shhh no.
99	Fareena	...with the cardboard it goes up and down.
100	Gilly	Ma'am I have to tell you something. (Pointing at her foot). Inaudible.
101	Amna	Okay okay, that's not related right now; it can wait. Okay, guys, so once again sorry, Ira. What was the difference? Listen to Kulsoom's answer.
102	Kulsoom	When the cardboard was covering the hole, it is lighter. The cardboard wasn't covering the hole, it was louder.
103	Amna	So what do you think is the purpose of the hole then?
104	Ibrahim	It bounces inside the sound hole and comes back. When you add this one, it doesn't go inside, it just goes up.
105	Amna	Okay, that's a really good way of putting it. I want you to remember what we just did here and will explain what exactly is happening as well.

6.4 Summary of results for RQ1

The results show that PD is effective in supporting teachers to develop the adaptive expertise to contingently respond to dynamic student talk in the moment by widening, deepening, maintaining, and shaping the dialogic space. ENA showed significant difference in the response patterns of the three teachers before and after the PD, both visually and statistically. Before the PD, Fatima conceptualised discussion as an interaction with students and focused on initiating the talk and providing feedback without student sense-making. After the PD, she positioned discussion as an opportunity for students to make sense of their experience in the field trip in relation to the scientific topic they were investigating. In her post-PD discussion, she shifted towards maintaining and widening, initiating and widening the dialogic space to achieve a balance between authoritative and dialogic discourse. Before the PD, Minahil framed her discussion as an interactive lecture, and her response alternated between initiate and feedback. After the PD, she framed her discussion as a consolidation discussion, in which she focused on maintaining and widening the dialogic space by following students' ideas and observations. Finally, Amna focused on maintaining and widening her pre-PD discussion, which could be characterised as a popcorn discussion, where students take turns to voice their thoughts without making connections to each other's ideas. In her post-PD discussion, she focused on maintaining the dialogic space by taking up students' queries and deepening it by challenging students' current conceptions. The next chapter answers Research question 2 to understand how the PD works in terms of the design and theoretical conjectures.

Chapter 7 Phase 3: How did the PD work? Analysis and results for RQ2

In this chapter, I answer Research question 2 and discuss the mechanisms of the PD that supports teachers in improving contingent responsiveness. To uncover the mechanisms that led to the change in teachers' practice, this research used conjecture maps as a systematic way to map out the path from design features to intervention outcomes (Sandoval, 2014). The **design features** were hypothesised to produce the **mediating processes**, forming the **design conjecture**. The mediating processes were hypothesised to produce the **desired outcomes**, forming the **theoretical conjecture**. According to Sandoval (2014), to test design conjecture, the first step is to identify whether mediating processes in fact emerge, and this provides evidence to trace that process back to designed features. As with design conjectures, evidence is needed to trace the outcome to the mediating process for theoretical conjectures. Research question 2 is answered in terms of the design conjectures and theoretical conjectures.

Research question 2: What are the mechanisms that support teachers in developing contingent responsiveness?

a) How did teachers improve their contingent responsiveness in relation to the mediating processes? (Theoretical conjectures)
b) How did teachers improve their contingent responsiveness in relation to the design features of the PD (Design conjectures)?

To test design conjecture, the first step is to identify the mediating process that emerges and provides evidence to trace that process back to the designed features. Evidence is needed to trace the outcome to the mediating process for theoretical conjectures. To attribute causal process, Sandoval (2014) made a distinction between Maxwell (2004)'s epistemology of scientific realism versus the traditional view of causality regularity identified with David Hume. According to the scientific realism view, a causal process can be observed and is not limited to inference through the regular co-occurrence of two events. Furthermore, Sandoval (2014) highlighted the distinctions between design features and variables. A design feature, such as collaborative inquiry, is not a variable, but a complex form of activity. Therefore, design should be understood as the interactions of different design features rather than the testing for variable effects.

7.1 Data sources

To observe the interaction among different design features, a variety of data sources were used, including both self-reported and direct observation:

1) The artefacts teachers produced during the workshop included their note catcher, collective reflections, and individual reflections
2) Post-workshop feedback forms and post-simulation feedback forms
3) Teachers' post-simulation reflection
4) Teachers' reflections about the PD during the post-PD retrospective interview
5) Video recordings of teachers leading discussions in the simulation
6) Teachers' pre- and post-PD discussion in the real classroom

7.2 Methods of analysis

A combination of systematic coding, content analysis, and epistemic network analysis (ENA) was used to identify whether the hypothesised mediating processes emerged and how they were connected to the design features and the outcome. Content analysis is a research technique for making replicable and valid inferences from texts to the contexts of their use, which involves specialised procedures (Krippendorff, 2019). Content analysis can be both quantitative (occurrence of certain words) (Neuendorf, 2017), and qualitative (describing and conceptualising meaning in the data)(Schreier, 2020). Content analysis involves either 1) the frequency of certain words, phrases, and other linguistic sets, or 2) the use of an established coding framework to generate measurements from qualitative materials (Byrne, 2017).

In the final version of the conjecture map, I identified five mediating processes:

1) Adopting dialogic framings of discussions
2) Developing fluency with talk moves
3) Deploying flexible attention
4) Engaging in knowledge-based reasoning
5) Experiencing metaphoric resonance

In this study, different coding frameworks were developed to systematically identify the emergence of each of mediating processes. For example, one hypothesised mediating process is "developing fluency with a repertoire of talk moves". To identify the emergence of teachers' fluency with talk moves, I systematically coded teachers' use of talk moves in pre-and post-PD discussions and compared the frequency. Table 7.1 summarises the mediating processes, data sources, and the codes used in the coding scheme.

Table 7.1 Summary of data sources and codes to identify the emergence of mediating processes

Mediating Process	Data source	Codes
Adopting of dialogic framings of discussions	Pre- and Post-PD science discussions	Mortimer and Scott's communicative approach 1) Interactive 2) Non-interactive 3) Dialogic 4) Authoritative
Developing fluency with a repertoire of techniques (i.e., talk moves)	Simulation sessions and Pre- and Post-PD science discussions	1) Open-ended question 2) Think Time 3) Say more (elaborate) 4) Add-on and build on 5) Press 6) Challenge (counter argument) 7) Synthesise 8) Summarise 9) Revoice/invite revoice 10) Focus 11) Rules of participation 12) Practice of science (Appendix 12)
Deploying flexible attention	Pre- and Post-PD science discussions	1) Classroom climate 2) Pedagogy 3) Student characteristics 4) Student science idea 5) Student lived experiences 6) Classroom equity (Appendix 4)
Experiencing metaphoric resonance	Post-PD retrospective interview	Teachers' mentions of experiencing metaphoric resonance, i.e., making

		connections between the current situation and their experience during the PD.
Engaging in knowledge-based reasoning	Post-PD retrospective interview	1) Knowledge about students 2) Content Knowledge 3) Pedagogical knowledge 4) Pedagogical content knowledge (Appendix 5)

In this chapter, I first identify whether each of the five mediating processes, in fact emerges before testing its associated theoretical conjecture and design conjectures.

7.3 Adopting dialogic framings

The PD introduced teachers to three types of dialogic framings in science discussion: elicitation discussion, consolidation discussion, and explanation discussion. Teachers' adoption of dialogic framings along the dialogic and interactive dimensions of Mortimer and Scott's (2003) communicative approach was evident in their post-PD discussion. Fatima and Minahil framed their discussion as a consolidation discussion.

Fatima's discussion explored the questions "what did we see on the field trip?" and "what can we do about it?" Minahil's discussion revolved around three questions, "what did we see during the field trip", "why did people litter", and "what can we do with trash?". Amna's framing was more closely aligned with an elicitation discussion, aiming to uncover student ideas about the origin of sound by demonstrating and comparing how sound is made in a guitar and a drum. During these post-PD discussions, students were positioned as sense-makers who contribute ideas and work on ideas together. In contrast, the pre-PD discussions of Fatima and Minahil could be characterised as interactive lectures, where the teachers were delivering a lecture whilst interacting with students. Amna's pre-PD discussion could be described as a popcorn discussion, where the teacher asked each individual student about their ideas without making use of student ideas and moving their thinking forward. Table 7.2 summarises teachers' framings of the pre- and post-PD discussions. In conclusion, the contrast in teachers' framing before and after the PD shows that teachers adopted dialogic framings after the PD.

Table 7.2 Teachers' framings of the pre- and post-PD discussions

Teacher	Pre-PD Framing	Post-PD Framing
Fatima	Interactive lecture (Interactive-authoritative)	Consolidation discussion (Interactive-dialogic)
Minahil	Interactive lecture (Interactive-authoritative)	Consolidation discussion (Interactive-dialogic)
Amna	A mix of popcorn discussion and lecture (Interactive- authoritative)	Elicitation discussion (Interactive-dialogic)

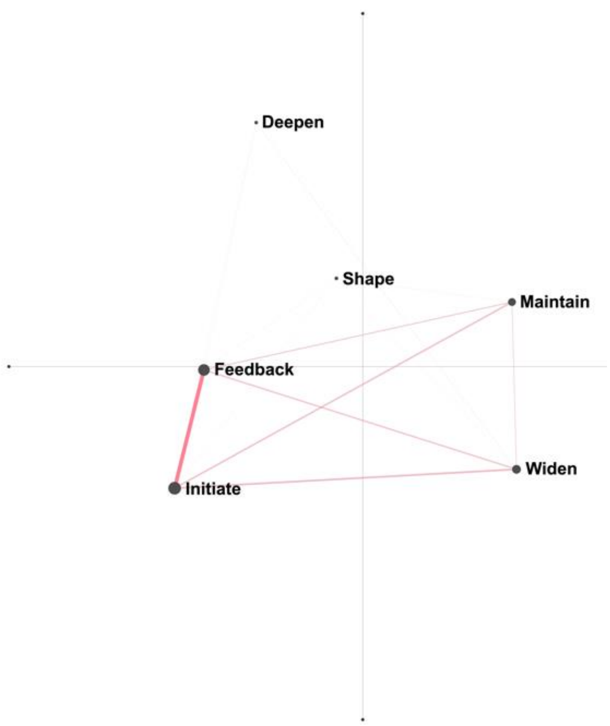
7.3.1 Theoretical conjecture 1: [Adopting dialogic framings] → [CR]

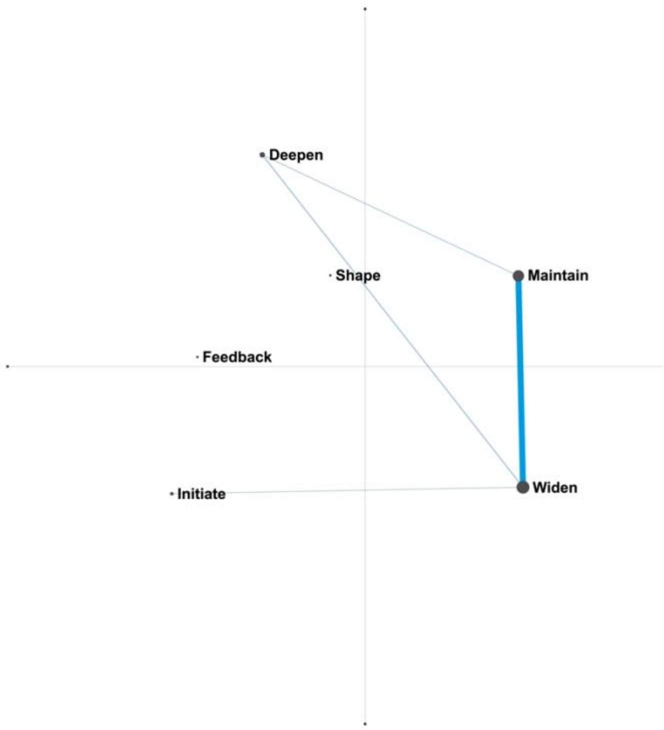
The first theoretical conjecture is that adopting dialogic framings can lead to teachers' contingent responsiveness. Evidence for this theoretical conjecture is found in the drastic shift of teachers' response patterns in the pre-PD discussion and Simulation 2. As discussed earlier, teachers' pre-PD discussion fell under the interactive-authoritative dimensions of the communicative approach. In the simulation, the framings for the discussion were provided for teachers as part of the task rather than having teachers frame their own discussions. The framing of Simulation 2 is for teachers to lead an elicitation discussion to uncover students' initial ideas about the puzzle 'the ships in the field'. Before Simulation 2, teachers only had two workshops and one orientation simulation. Nonetheless, there was a drastic shift in teachers' response patterns in Simulation 2 compared with their pre-PD discussion. All three teachers' response patterns in Simulation 2 and pre-PD are compared below.

7.3.1.1 Fatima's response pattern in pre-PD discussion and Simulation 2

Figure 7.1 and Figure 7.2 compare Fatima's response pattern during the pre-PD discussion and Simulation 2. Fatima's pre-PD response focused on initiate and feedback (M=0.36) whereas her response pattern in Simulation 2 drastically shifted towards maintain-widen (M=0.64).

Figure 7.1 Fatima's pre-PD response pattern   *Figure 7.2 Fatima's Simulation 2 response pattern*





The visual differences between Fatima's response patterns are also confirmed by statistical tests. Along the x-axis, a two-sample t-test assuming unequal variance showed **Fatima's pre-PD discussion** (mean=-0.33, SD=0.42, N=70 was **statistically significantly different** at the alpha=0.05 level from **Fatima's Simulation 2** (mean=0.63, SD=0.51, N=22; t(30.48)= -8.02, p=0.00, Cohen's d=2.17). Along the y-axis, a two-sample t-test assuming unequal variance showed Fatima's pre-PD discussion (mean=-0.21, SD=0.42, N=70 was **not statistically significantly different** at the alpha=0.05 level from **Fatima's Simulation 2** (mean=-0.15, SD=0.26, N=22; t(56.90)= -0.84, p=0.40, Cohen's d=0.16).

Fatima's response pattern in Simulation 2 aligned with the framing of the elicitation discussion, which was to uncover a variety of student ideas, perspectives, and experiences prior to an investigation/at the beginning of an inquiry. Therefore, Fatima kept maintaining and widening the dialogic space to signal the ongoing nature of the dialogue and to bring in more student perspectives.

7.3.1.2 Minahil's response pattern in pre-PD discussion and Simulation 2

Figures 7.3 and 7.4 compare Minahil's response pattern during the pre-PD discussion and Simulation 2. Minahil's pre-PD response focused on initiate-feedback (M=0.23) whereas her response pattern in Simulation 2 shifted towards maintain-widen (M=0.29) and maintain-feedback (M=0.20).

Figure 7.3 Minahil's pre-PD response pattern

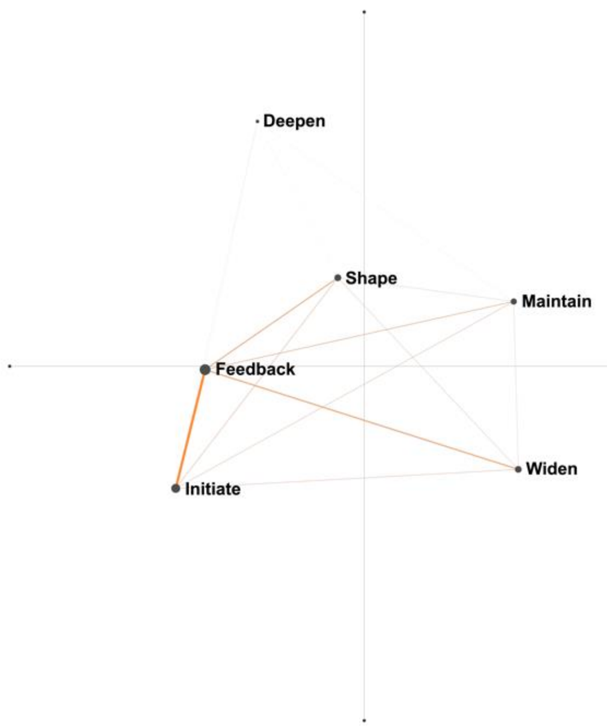
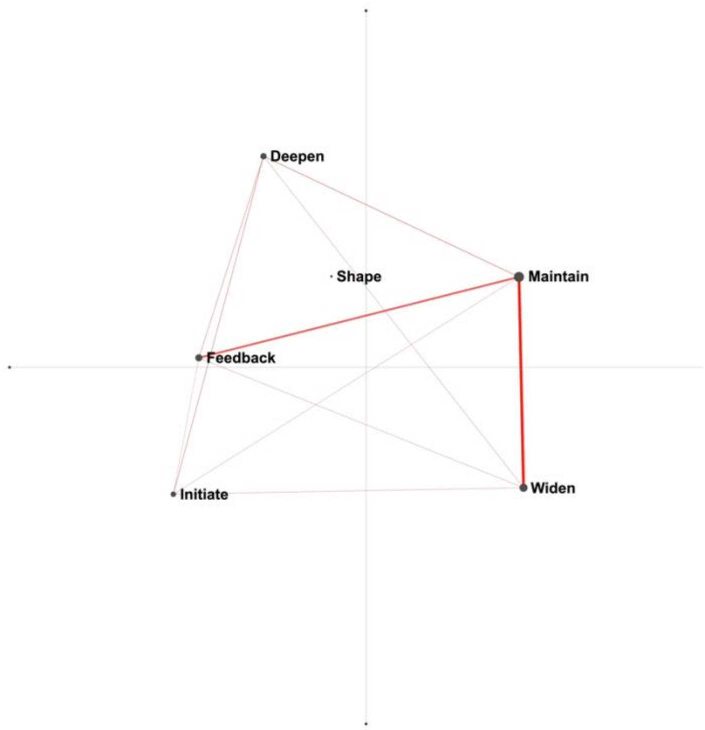


Figure 7.4 Minahil's Simulation 2 response pattern



The visual differences between Minahil's response patterns are also confirmed by statistical tests. Along the x-axis, a two sample t-test assuming unequal variance showed **Minahil's pre-PD discussion** (mean=-0.24, SD=0.34, N=51 was **statistically significantly different** at the alpha=0.05 level from **Minahil's Simulation 2** (mean=0.15, SD=0.60, N=21; t(25.39)= -2.86, p=0.01, Cohen's d=0.93). Along the y-axis, a two sample t test assuming unequal variance showed **Minahil's pre-PD discussion** (mean=-0.10, SD=0.36, N=51 was **not statistically significantly** different at the alpha=0.05 level from **Minahil's Simulation 2** (mean=0.10, SD=0.44, N=21; t(31.67)= -1.78, p=0.09, Cohen's d=0.50).

Based on the strong connection between maintain-widen (M=0.23), it was evident that Minahil tried to elicit a variety of student ideas during the discussion, which was coherent with the framing of the elicitation discussion. During the retrospective interview, Minahil expressed that it is important to her as a teacher to support students to reach the intended scientific concepts, which explains the connection between maintain-feedback (M=0.20)—keeping dialogic space open whilst guiding students toward the scientific concepts that she intended to teach.

7.3.1.3 Amna's response pattern in pre-PD discussion and Simulation 2

Figures 7.5 and 7.6 compare Amna's response pattern during the pre-PD discussion and Simulation 2. Amna's pre-PD response focused on maintain-widen (M=0.13), and her response pattern in Simulation 2 showed a strong connection between maintain-widen (M=0.21) in addition to widen and deepen (M=0.24).

Despite the visual difference, the statistical tests showed that overall the difference between Amna's pre-PD discussion and Simulation 2 was not statistically significant. Along the x-axis, a two-sample t-test assuming unequal variance showed **Amna's pre-PD discussion** (mean=0.03, SD=0.42, N=106) was not statistically significantly different at the alpha=0.05 level from **Amna's Simulation 2** (mean=0.16, SD=0.39, N=33; t(58.00)= -1.66, p=0.10, Cohen's d=0.32). Along the y-axis, a two-sample t-test assuming unequal variance showed Amna's pre-PD discussion (mean=0.02, SD=0.31, N=106) **was not statistically significantly** different at the alpha=0.05 level from **Amna's Simulation 2** (mean=0.09, SD=0.26, N=33; t(62.53)= -1.30, p=0.20, Cohen's d=0.24).

Figure 7.5 Amna's pre-PD response pattern

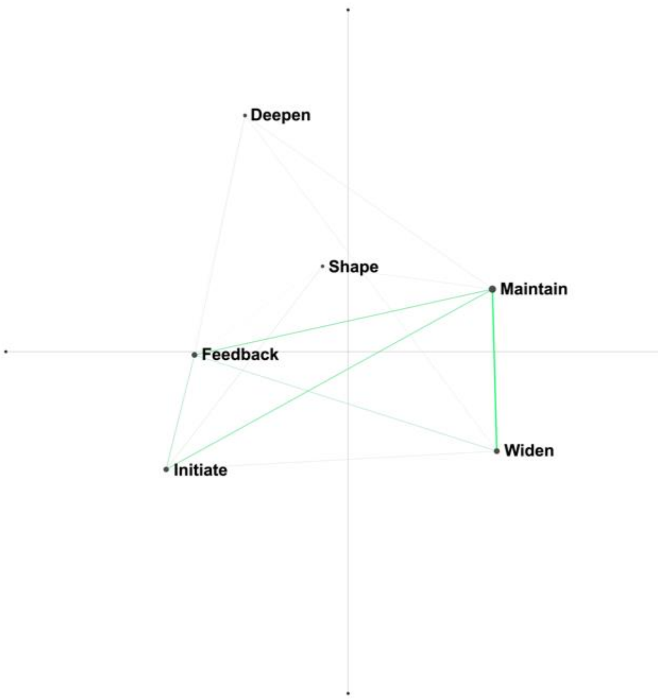
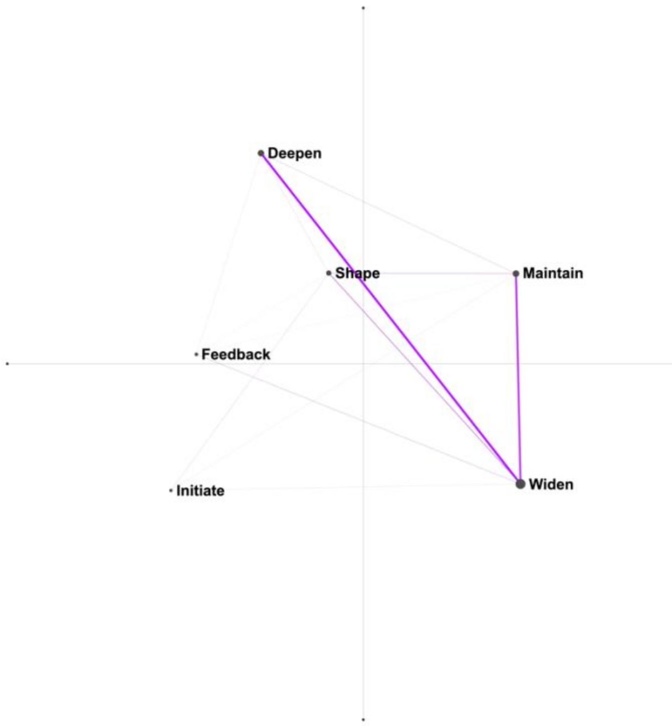


Figure 7.6 Amna's Simulation 2 response pattern



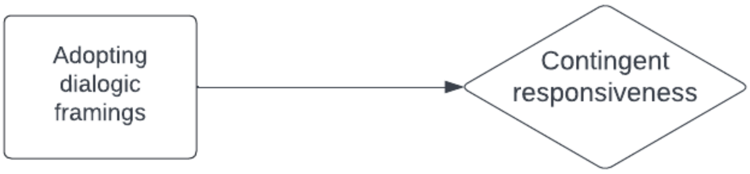
Based on the strong connection between maintain-widen (M=0.21) in Simulation 2, it was evident that Amna followed the framing of an elicitation discussion to uncover a variety of student ideas. Unlike her pre-PD discussion where she only focused on eliciting student ideas, in Simulation 2, she tried to deepen the dialogic space by having students form potential hypotheses to explain their ideas. The excerpt in Table 7.3 shows how Amna first widened the dialogic space to ask Dev for his idea and then deepened it by encouraging Dev to come up with a potential hypothesis for his idea. Because Amna's pre-PD discussion also focused on elicitation, it explains why her response pattern in the pre-PD discussion and Simulation 2 did not show a difference that is statistically significant.

Table 7.3 Excerpt of Amna's Simulation 2

33	Amna	Alright, so Dev, you're up. So anything that we might have missed already?
34	Dev	Okay. Um, well, um, this is, um, well, it's not like, new. But I was thinking, um, because Savannah, you said they're just wearing normal clothes. And if it was snow, like, maybe they'd be wearing like, something warm. So maybe it's not snow, maybe at salt.
35	Amna	Interesting. So interesting. So salt, so where could the salt has come from?

In summary, the drastic shift in teachers' response pattern in Simulation 2 provided evidence that teachers' responses are partly driven by their framing of the discussion since it is implausible for teachers to shift their response pattern to such an extent only after two workshops and one simulation for orientation purpose. Therefore, the findings provide support for the first theoretical conjecture that adopting dialogic framings can lead to teachers' contingent responsiveness. Figure 7.7 shows the mapping of adopting dialogic framing to CR.

Figure 7.7 Theoretical conjecture: [Adopting dialogic framings] → CR



7.3.2 Design conjecture 1: [MRS] → [Dialogic framings]

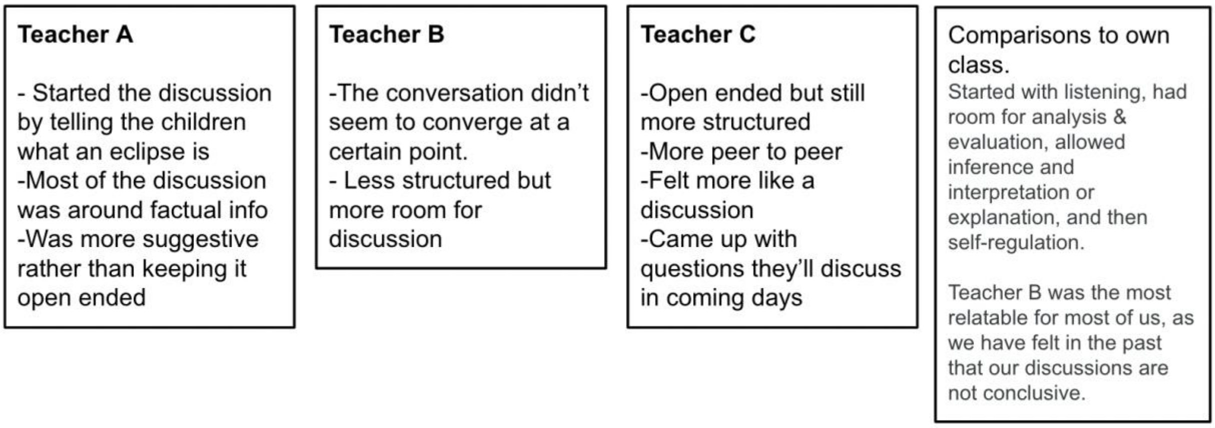
Design conjecture 1 hypothesises that mixed-reality simulation can support teachers to adopt dialogic framings. The simulation tasks were designed to expose teachers to a variety of dialogic framings in science discussions. To complete the tasks, teachers had to adopt the framing. Teachers' adoption of dialogic framing was evident in their response pattern (see discussion and evidence in Section 7.3.1). For instance, Fatima, Minahil, and Amna all focused on widening and maintaining the dialogic space in Simulation 2, which aligned with the framing of an elicitation discussion to uncover the diversity of students' ideas. Therefore, there is evidence to support design conjecture 1, i.e., mixed-reality simulation can support teachers to adopt dialogic framings.

7.3.3 Design conjecture 2 [Case studies] & [Guided collaborative inquiry] → [Adopting dialogic framings]

Design conjecture 2 hypothesises that case studies in the guided collaborative inquiry can support teachers to adopt dialogic framings. In Workshop 2, teachers were provided with three case studies of teachers leading discussions on the same topic with different framings. Teachers read the case studies and conducted a guided collaborative inquiry with their peers in breakout rooms. Appendix 10 shows the guidance provided to teachers during their collaborative inquiry, including discussion prompts, suggested time, discussion routine, and the product.

In teachers' collective notes in their note catcher during the guided collaborative inquiry, it was evident that teachers recognised different types of framings in a discussion and connected them to their own teaching experience. The note catcher in Figure 7.8 shows teachers extracted the framings of each discussion. They noted that Teacher A was focused on providing students with information (interactive lecture), whereas Teacher B elicited student ideas but did not make use of them in a productive way (popcorn discussion), and Teacher C elicited and made use of student ideas (elicitation discussion). Furthermore, Teachers' feedback in Workshop 2 also reflected how the case studies and collaborative inquiry supported their learning. When asked "what is helping me to learn in the workshop?", 4 teachers (67%) of the teachers specifically mentioned the case studies and collaborative inquiry.

Figure 7.8 Teachers' note catcher in Workshop 2



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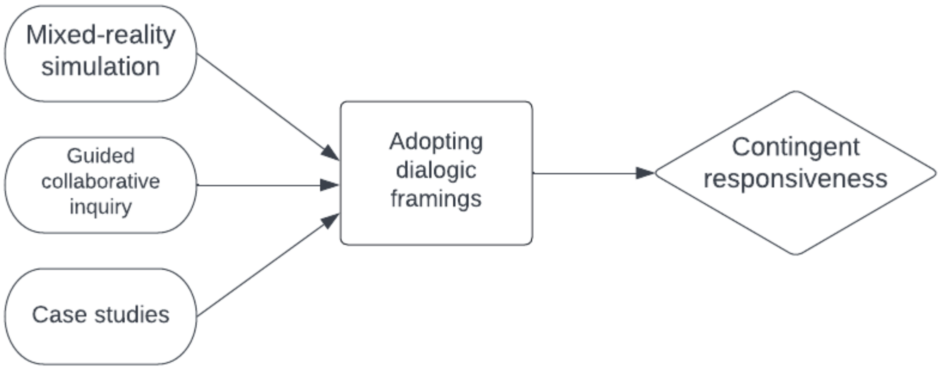
In summary, teachers' note catcher as a learning artefact and their anonymous feedback provide evidence to support Design conjecture 2, i.e., case studies in the guided collaborative inquiry can support teachers to recognise and adopt dialogic framings. Figure 7.9 summarises the design conjectures and theoretical conjectures related to the mediating process, i.e., adopting dialogic framings.

Figure 7.9 Design and theoretical conjectures related to adopting dialogic framings



7.4 Developing fluency with talk moves

The PD provided teachers with a talk move toolkit that contains a list of talk moves and how to use them as part of the workshop and simulation guide. Teachers' development of fluency with talk moves was evident in the increasing use of talk moves after the PD. The transcripts of teachers' pre- and post-PD were systematically coded with 12 talk moves that were introduced in the PD. 10% of the transcript was independently coded by another doctoral student and myself. Cohen's Kappa was computed for each code was computed as shown in Table 7.4. The results showed that there is substantial agreement between the two coders. Because not all talk moves were present in the discussion, some codes were absent, which was indicated as N/A.

Table 7.4 Inter-rater reliability for talk moves

Talk moves	Cohen's Kappa
Open-ended Question	0.803
Uptake	0.655
Think time	N/A
Say more	0.843
Add-on/Build-on	0.784
Press	0.623
Challenge	1.00
Synthesise	N/A
Revoice/Invite revoice	0.673
Summarise/Invite summary	0.655
Remind ground rules	0.787

7.4.1 Fatima's talk moves

Fatima used a total of 12 talk moves in her pre-PD discussion and 29 talk moves in her post-PD discussion. As shown in Figure 7.10, Fatima used revoice, add-on/build-on, say more in the post-PD discussion compared to the pre-PD discussion. Figure 7.11 shows the total number of various talk moves that Fatima used throughout the PD, including her pre- and post-discussion and three simulations. It was evident therefore that Fatima developed fluency with talk moves to an extent, especially with the revoice, add/build on, open-ended questions, and say more.

Figure 7.10 Fatima's talk moves before and after the PD

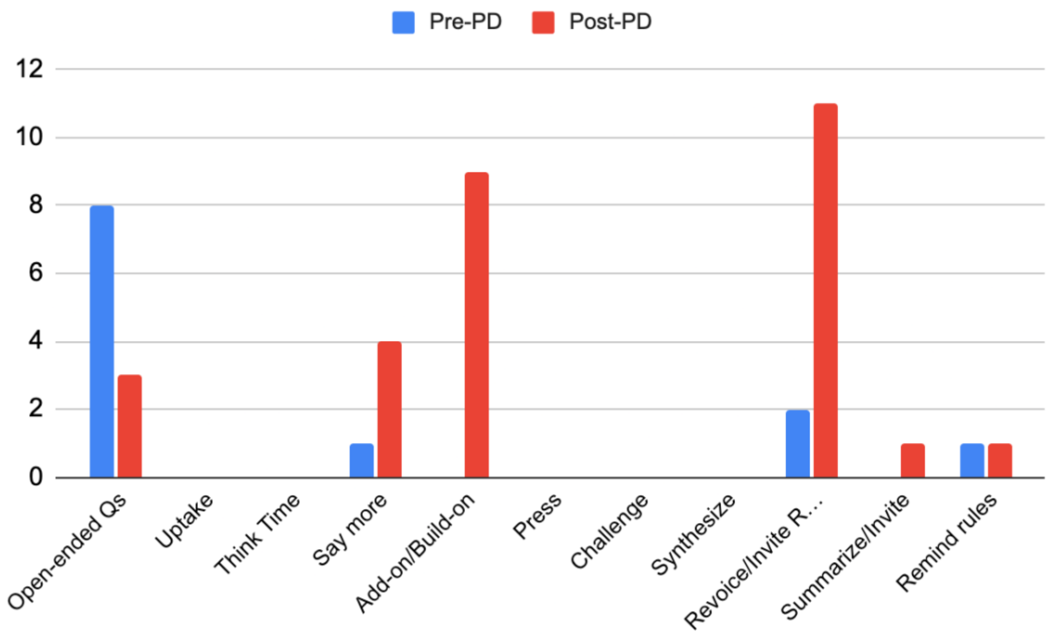
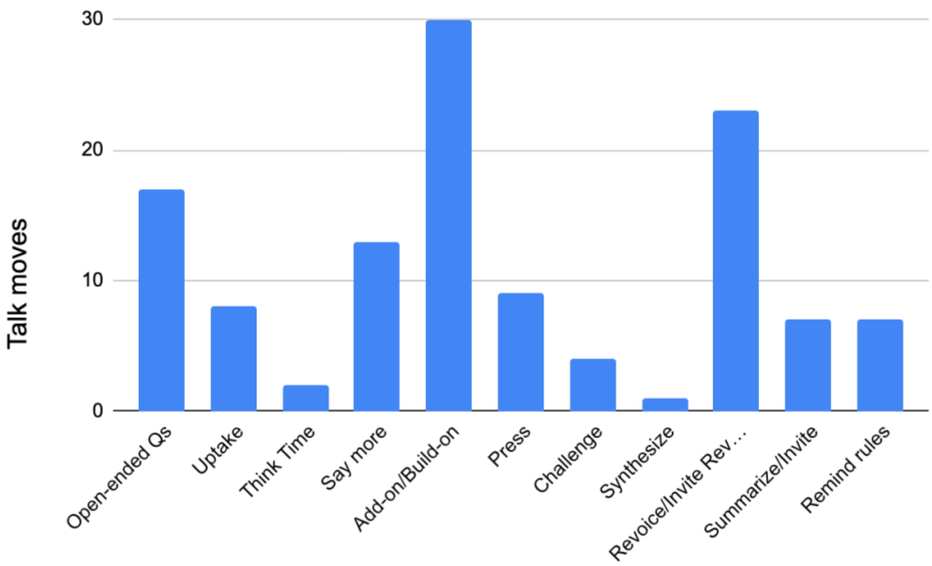


Figure 7.11 The variety of Fatima's talk moves



7.4.2 Minahil's talk moves

Minahil used a total of 10 talk moves in the pre-PD discussion and 36 in the post-PD discussion. As shown in Figure 7.12, the diversity of talk moves used was also increased in addition to frequency. Notably, Minahil used the talk move revoice as frequent as 13 times. In the retrospective interview, Minahil also highlighted revoice as a talk move that she personally used a lot to keep students on the same page during the discussion given the young age of her students and the distractions present in a classroom environment (there are windows between classrooms, so students could get distracted).

Figure 7.13 shows the total number of various talk moves that Minahil used throughout the PD, including her pre-and post-PD discussion and three simulations. It was evident therefore that Minahil developed fluency with a variety of talk moves, especially with the revoice, add/build on, press, summarise/invite summary, and open-ended questions.

Figure 7.12 Minahil's talk moves before and after the PD

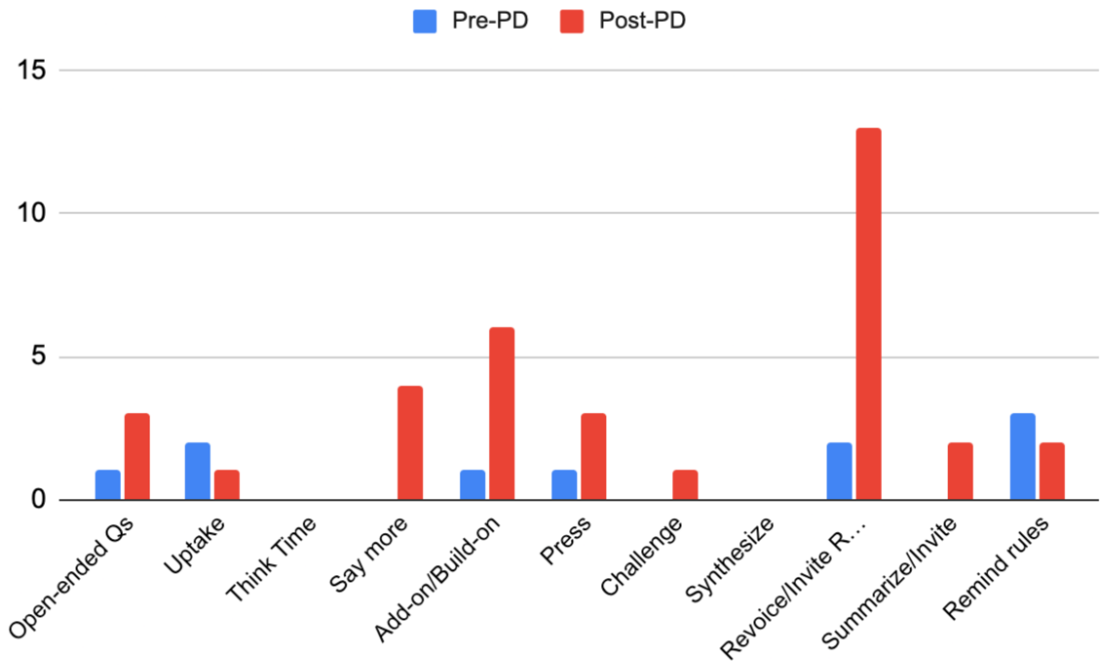
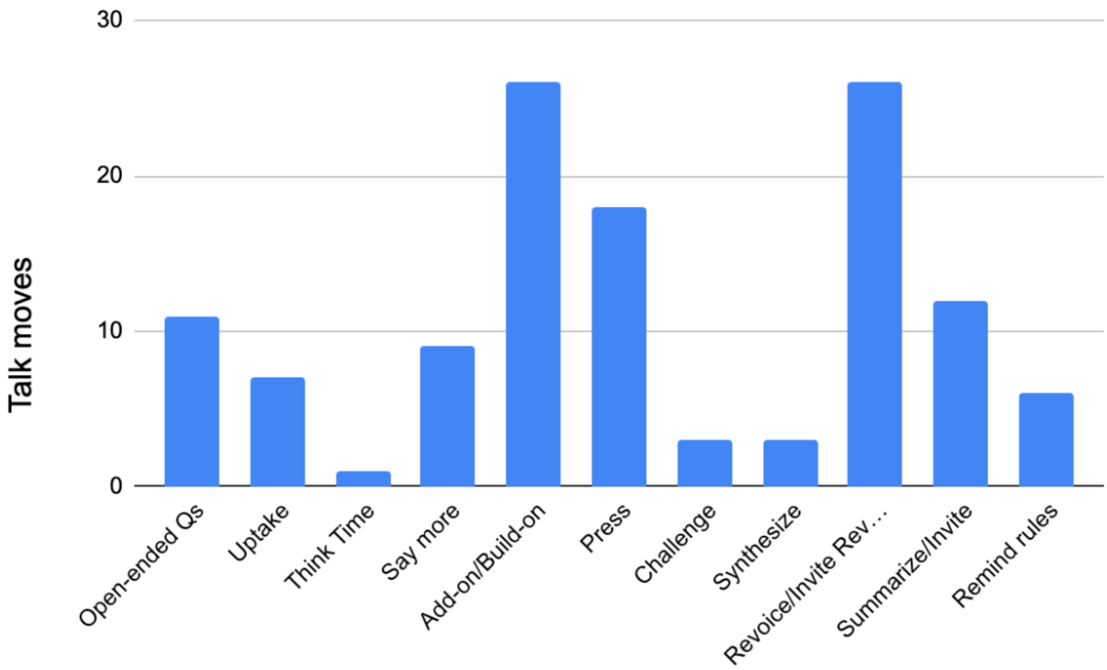


Figure 7.13 The variety of Minahil's talk moves



7.4.3 Amna's talk moves

Amna had fluency with talk moves to an extent before the PD. She used a total of 15 talk moves in the pre-PD discussion and 18 in the post-PD discussion. Though the frequency of talk moves did not increase significantly, the talk moves that she used in the post-PD were slightly more diverse than the pre-PD. For instance, Amna used the talk move 'synthesise; three times in the post-PD discussion which was not present in the pre-PD discussion (see Figure 7.14).

Figure 7.14 Amna's talk moves before and after the PD

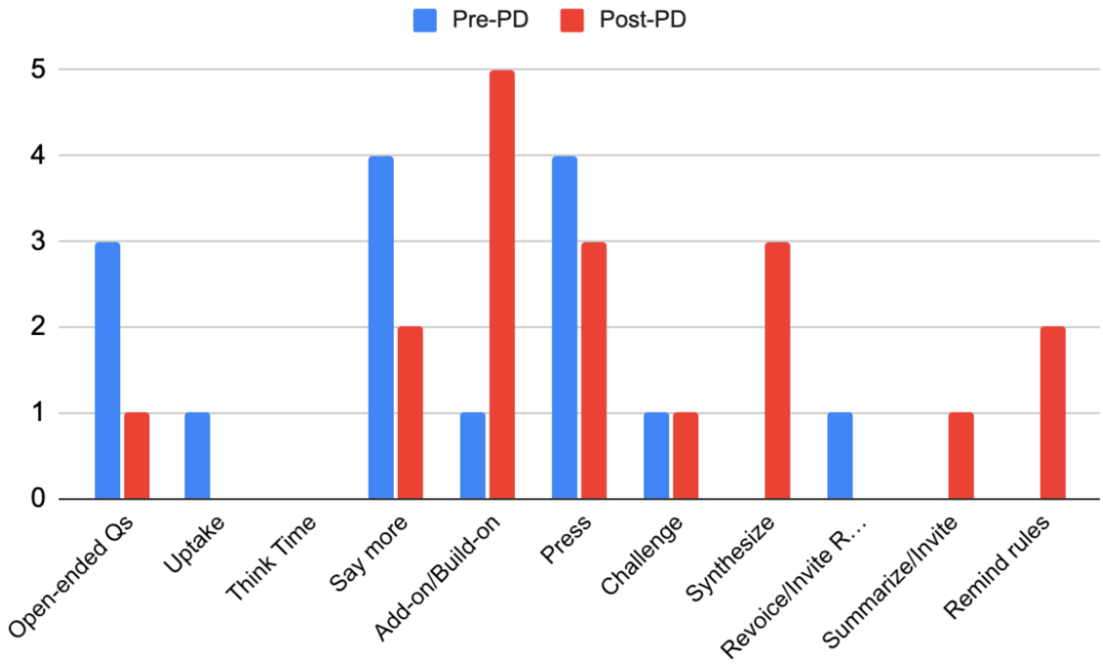
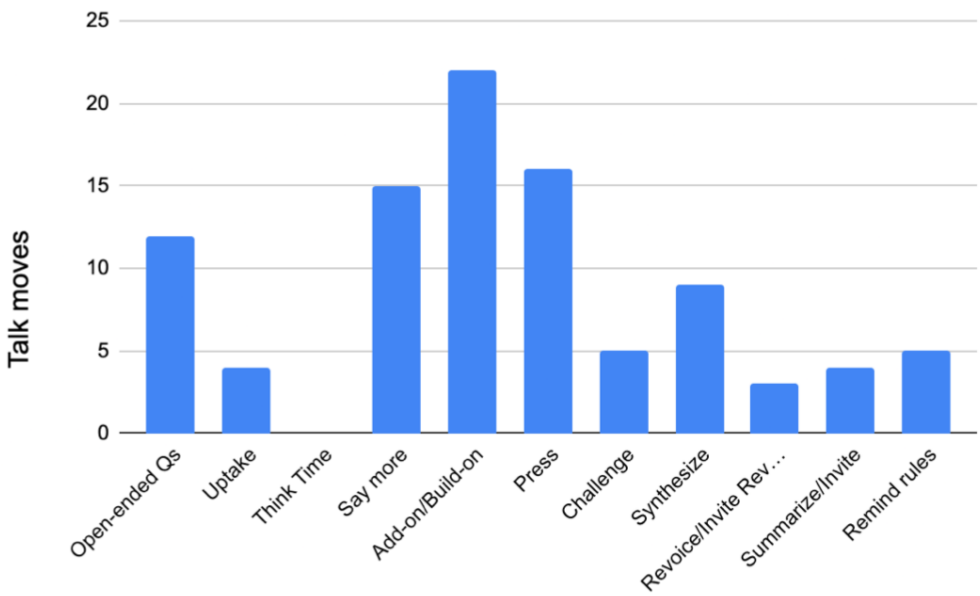


Figure 7.15 shows the total number of various talk moves that Amna used throughout the PD, including her pre- and post-discussion and three simulations. It is evident therefore that Amna displayed fluency with talk moves and a relatively balanced profile among the talk moves.

Figure 7.15 The variety of Amna's talk moves



In summary, the increase in the frequency and diversity of talk moves applied by Fatima, Minahil, and Amna provide evidence in supporting the emergence of teachers developing fluency with talk moves as a mediating process.

7.4.4 Theoretical conjecture 2: [Develop fluency with talk moves] →[CR]

Theoretical conjecture 2 hypothesises that developing fluency with talk moves can lead to CR, i.e., the adaptive expertise to contingently respond to student talk to promote sense-making and equity. There is evidence in teachers' reflections during the asynchronous guided inquiry about how talk moves helped them to promote student sense-making in the asynchronous guided inquiry during Iteration 3.

Minahil described how she applied talk moves in the sequence of her instruction to promote sense-making:

> I use talk moves regularly in science class. I use 'think time' at the start of the class for 'recalling', during the class 'probing' and 'pressing' to get them involved and generate ideas, and towards the end, I use 'revoicing' to summarise.

Fatima stated that talk moves are helpful to promote student's understanding:

> Talk moves are very helpful in gauging the children's understanding of the concept being taught in the class. We usually use them throughout the class depending on the stage of the problem-based learning.

Amna expressed how she connected talk moves with dialogic functions for sense-making :

> Since we follow the design thinking phases in our problem-based learning. There are times when I will use various talk moves to deepen (build-on, pressing) or widen (say more, probe) their understanding of a concept.

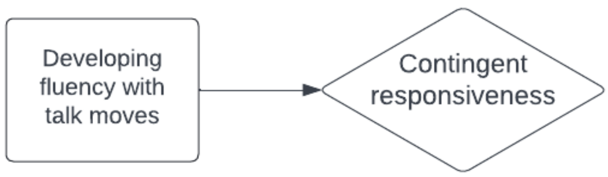
Furthermore, there is evidence in the post-PD discussion that teachers used talk moves to support equitable participation. For instance, in the retrospective interview, Fatima highlighted the diverse needs of her learners. She pointed out that some of her students were more eager to participate and share their ideas whereas others were shy and hesitant. The excerpt in Table 7.5 shows a moment that Fatima highlighted in the retrospective interview when one student Yumna interjected when another student Rimsha was taking her time to form her ideas. Fatima revoiced Rimsha's ideas to broadcast to the whole class, which also allowed her to sustain Rimsha's turn of talk, allowing equitable participation among the students.

Table 7.5 Excerpt in Fatima's post-PD discussion

Turn	Speaker	Utterance
3	Fatima	Okay reducing recycling reusing. What else do we mean by environment, Rimsha?
4	Rimsha	[speaking very quietly] hmmm environment means water…
5	Fatima	Water.
6	Rimsha	Air…
7	Fatima	Air.
8	Rimsha	hmmm….that…
9	Yumna	[interject] Ma'am.
10	Rimsha	Water, air, land…
11	Fatima	Land! Is everything in water, air, and land part of the environment?
12	Yumna	Ma'am!
13	Fatima	One second, Yumna.
14	Fatima	[going back to Rimsha], what do you think?
15	Rimsha	hmmm...Yes.

In summary, the evidence above supports Theoretical conjecture 2, i.e., teachers' fluency with talk moves allows them to contingently respond to student ideas to both promote student sense-making and equitable participation. Figure 7.16 shows the mapping of theoretical conjecture, i.e., developing fluency with talk moves as a mediating process to CR as the outcome.

Figure 7.16 Theoretical conjecture 2: [Develop fluency with talk moves] →[CR]



7.4.5 Design conjecture 3: [MRS] & [Talk moves] → Developing fluency with talk moves

Design conjecture 3 hypothesises that practising talk moves in the mixed-reality simulation can support teachers to develop fluency with talk moves over time. In the PD, mixed-reality simulations provided teachers with authentic and contextualised scenarios to practice using talk moves to promote student sense-making and classroom equity. Figures 7.17 and 7.18 show that Fatima and Minahil increasingly used more talk moves over time in the simulation. Figure 7.19 shows that Amna also consistently applied talk moves in the simulations with a slight increase compared to the pre-PD discussion.

Figure 7.17 Number of talk moves applied by Fatima over time

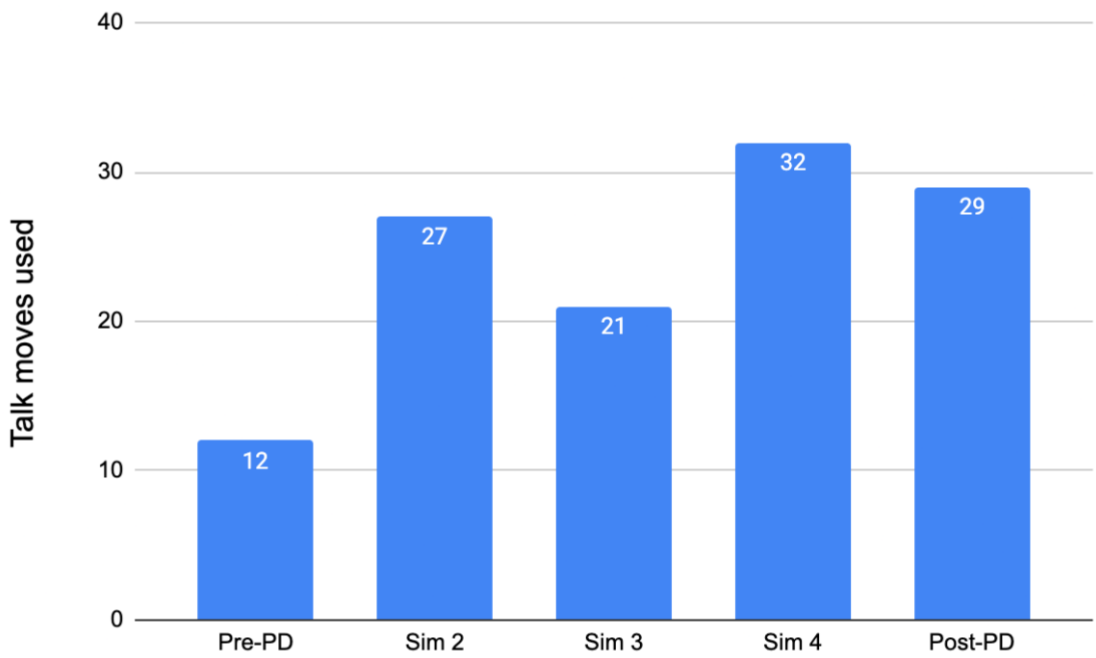


Figure 7.18 Number of talk moves applied by Minahil over time

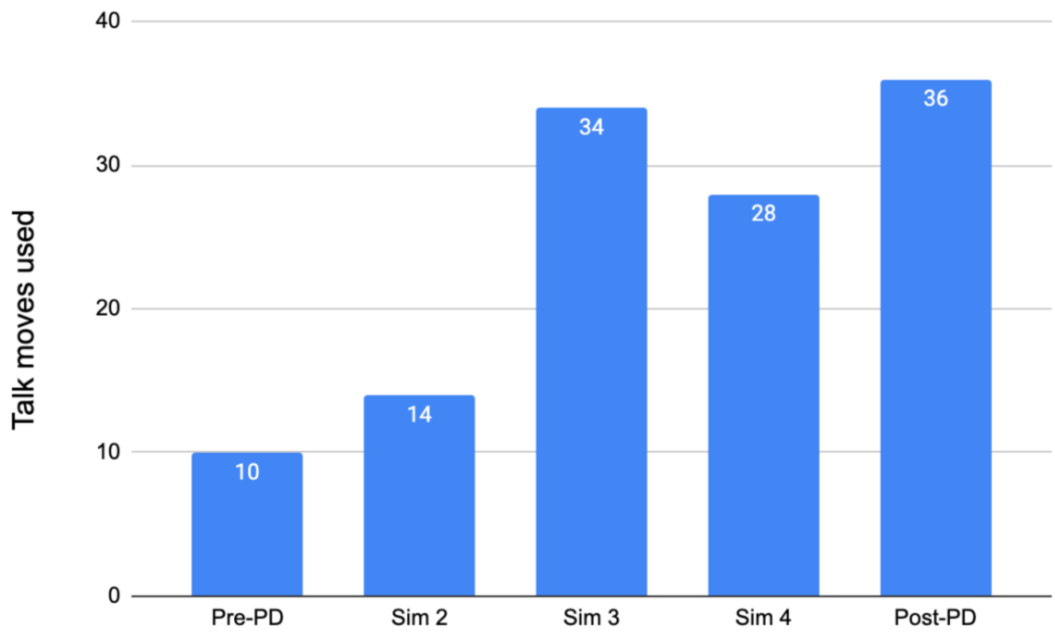
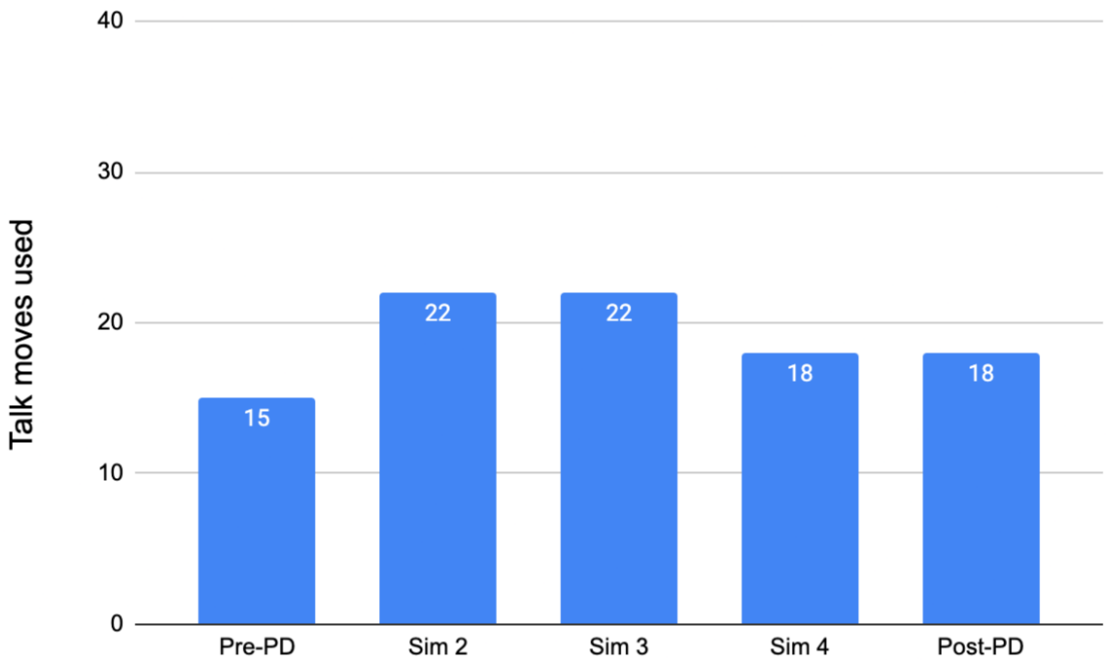


Figure 7.19 Number of talk moves applied by Amna over time

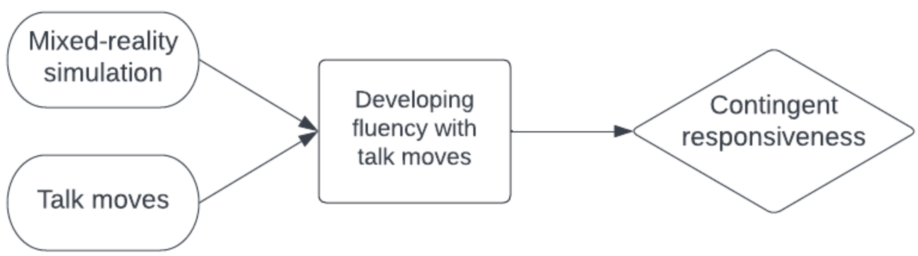


In the retrospective interview, Fatima commented on how the PD provided opportunities for practising talk moves in various contexts, which helped her to transfer her learning to the real classroom:

> The workshop was a very, very good experience, and they helped us practice a lot of talk moves with different types of discussions. It also helped us figure out when to have a consolidation [discussion] for example, or how to practise talk moves because we were mindfully practising the content…So it really helped us to kind of practice all those things mindfully in small chunks, try to bring them back to our classes, because when you practice something, and it, at least some of it stays with you, and consciously or unconsciously you start applying those things to your regular real-life classes as well. So that was really, really helpful.

In summary, teachers' increasing use of talk moves over time in the simulation provides evidence that practising talk moves in the simulation supports them to develop fluency. Figure 7.20 summarises the design conjectures and theoretical conjectures related to developing fluency with talk moves.

Figure 7.20 Design and theoretical conjectures related to developing fluency with talk moves



7.5 Deploying flexible attention

Teachers' attention during their class discussion was identified from retrospective interviews when the teacher and researcher watched the class discussion recording together. Teachers paused the video at any moment they found interesting and noteworthy and spoke out loud about the moment. Luna and Sherin (2017) operationalised teachers' attention into four categories based on the topic of teachers' commentary about their classroom videos: 1) student characteristics; 2) classroom climate; 3) pedagogy; 4) student science idea. Furthermore, after observing and analysing 222 secondary lessons (1174 episodes) from 37 novice teachers, Thompson et al. (2016) found that there were three forms of responsive talk observed in classrooms that elevate the rigour of learning: 1) building on students' scientific ideas, 2) encouraging participation and building classroom community, and 3) leveraging students' lived experiences and building scientific stories. Building upon Luna and Sherin (2017), I drew on Thompson et al. (2016) and included two more dimensions: 5) student lived experience and 6) classroom equity.

I systematically coded teachers' attention in relation to the topic of their commentary during the retrospective interview according to the six dimensions of science class mentioned above (for the full coding scheme, see Appendix 4). 30% of the dataset was independently coded by another doctoral student and myself. Cohen's Kappa was computed for each code as shown in Table 7.6. There is substantial agreement for all codes except for the student science idea, which reached a moderate agreement. Not-applicable (N/A) indicates the absence of the code in the transcript. In the following sections, I compare and contrast the three teachers' attention before and after the PD to identify whether teachers started to deploy flexible attention during science class discussions.

Table 7.6 Inter-rater reliability for teachers' attention

Teachers' attention	Cohen's Kappa
Classroom Climate	N/A
Pedagogy	0.709
Student characteristics	1.00
Classroom equity	0.646
Student science idea	0.556
Student lived experiences	0.629

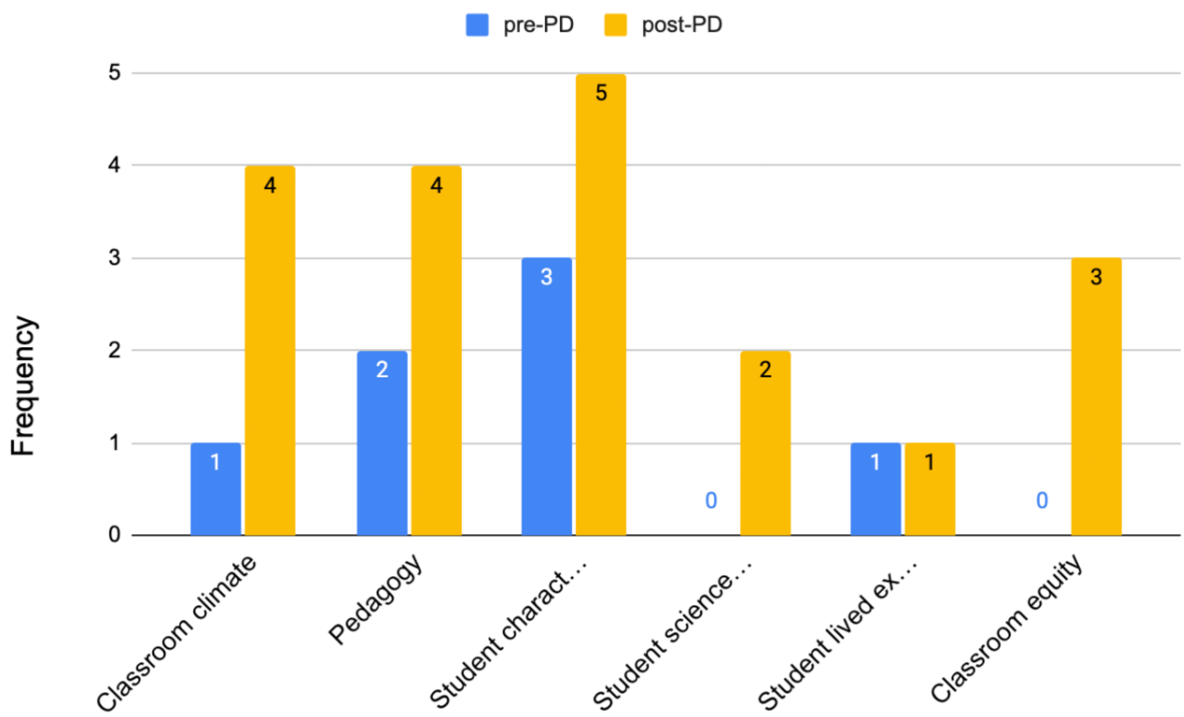
7.5.1 Fatima's attention before and after the PD

In the retrospective interview, seven targets of attention were identified in Fatima's pre-PD discussion.

It is important to note that Fatima came to the pre-PD retrospective interview with her co-teacher at that time (not Minahil or Amna), so the targets of attention came from both teachers. As shown in Figure 7.21, both teachers' attention was primarily on student characteristics and pedagogy. For instance, they would pause the video and comment on the characters and personalities of the students or their group of students in general. For instance, they paused at a moment when students were relating the story about the five senses to their own personal experiences. They noticed student characteristics and their lived experience in this instance:

> So this is something that we like, where they can relate whatever we are doing with their personal lives. So this helps [them] in remembering a lot of things. When they can relate a lot of the work we're doing in class with their personal lives, then they are able to remember more. So this is something we like about these kids, they just pick it up on their own. We didn't ask them at who wears glasses in their family or something. But they themselves they came up with [the idea that] my mother wears them and my father wears them; my brother and sister [wear them].

Figure 7.21 Distribution of Fatima's attention in the pre- and post-PD discussion



In Fatima's post-PD retrospective interview (which she attended by herself), 19 targets of attention were identified, where she focused primarily on student characteristics, pedagogy, classroom climate, and classroom equity (see Figure 7.21). Compared with pre-PD discussion, not only there is an increase in the frequency of her attention, but also in terms of diversity to include student science ideas and classroom equity. For instance, in the post-PD retrospective interview, Fatima highlighted a moment when one student, Yumna, was eagerly raising her hand to speak whereas another student, Rimsha, was slowly taking the time to form her ideas. She noticed both the diversity of student characteristics and classroom equity in this instance (for the transcript see Table 7.14):

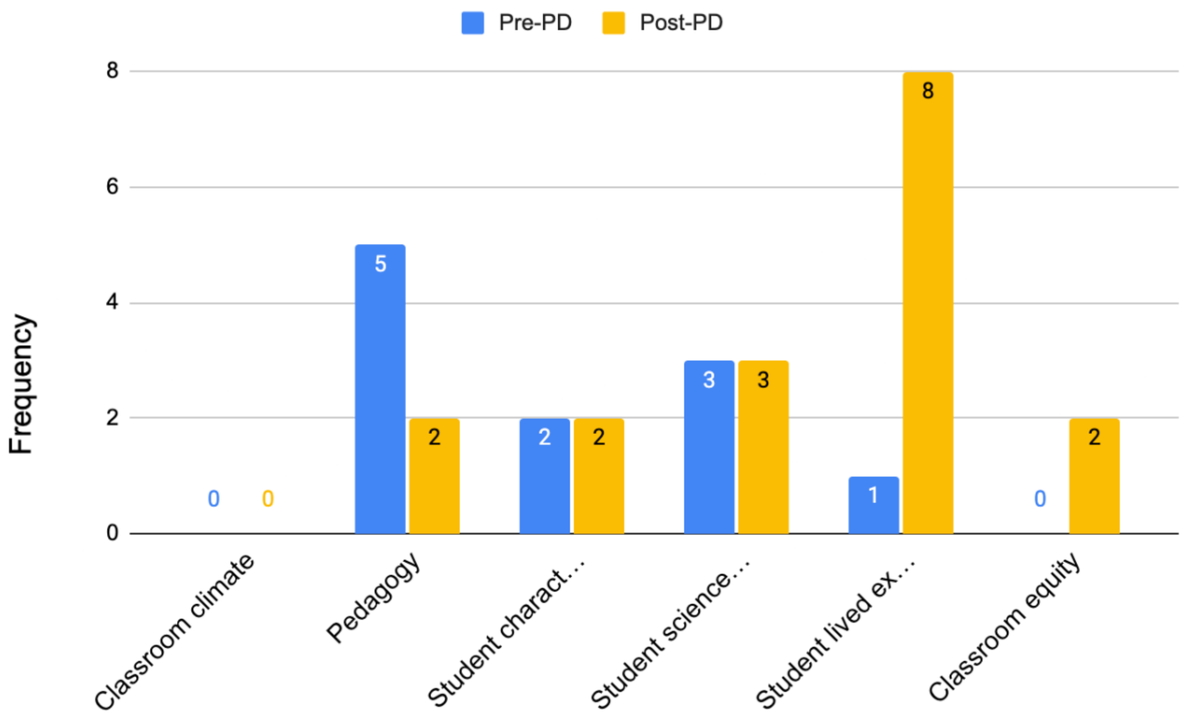
> Okay, so, Yumna is very outspoken, and she likes to speak a lot, but Rimsha the is one in the [colour] shirt…she's a little shy. So it takes her time to form sentences or, you know, she needs some time to actually process the thoughts if you ask her a question. When there's not enough time, and children at this age are so impatient. So that's one of the things that we struggle with. See Yuma's hand is up again because she wants to share again. Jaria the girl who is on this end, will answer now she has dyslexia she has trouble writing, and she speaks really well. But when she has to put her thoughts on paper. That is a struggle for her. You know we are still trying to find a balance between these children.

7.5.2 Minahil's attention before and after the PD

In Minahil's pre-PD retrospective interview, 11 targets of attention were identified, where she primarily focused on her pedagogy and student science ideas (see Figure 7.22). For example, during the retrospective interview, she paused the video at a moment where one student came up with the idea that people extract metaphoric rocks deep under the ground using a big machine and heat shield. Minahil noticed the student's science idea and her pedagogy in this instance about the extraction of metamorphotic rock and her pedagogical decision to not go into details about this concept. In the post-PD discussion, a total of 17 targets of attention were identified. Minahil's primary focus was on student lived experience and science ideas, and she also attended to classroom equity, which was not present in the pre-PD discussion. For instance, in the retrospective interview, Minahil showed her attention to classroom equity when she highlighted one student who did not speak in the discussion. She drew on her knowledge about the student to make the decision of not wanting to push her to participate at this moment:

> This girl in the yellow, this was I think her second or third day, so she was really shy, and she had moved from back from America, so that's why I was not pushing her too much to participate.

Figure 7.22 Distribution of Minahil's attention in the pre- and post-PD discussion

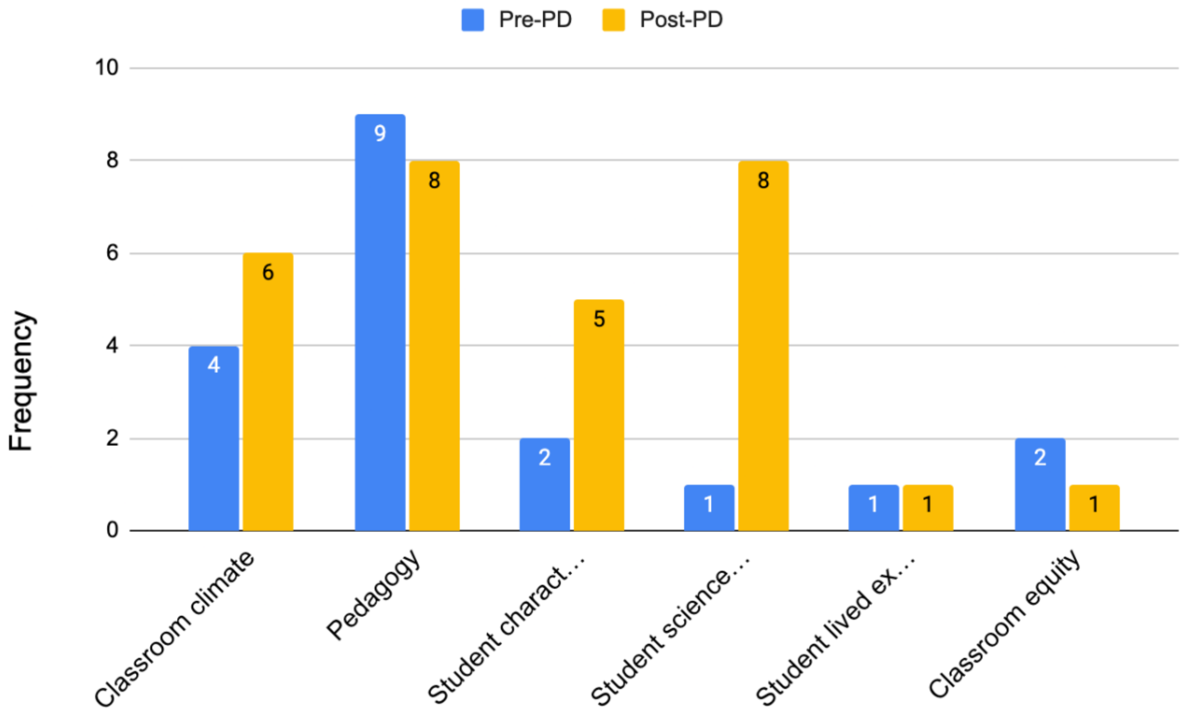


7.5.3 Amna’s attention before and after the PD

In the retrospective interview, a total of 19 targets of attention were identified in Amna’s pre-PD discussion. Amna’s attention in the pre-PD discussion was mainly on pedagogy and classroom management (Figure 7.23). For instance, in the retrospective interview, Amna underlined a moment in her discussion, when she pressed one student for his reasoning for several turns of talk. In this moment, she focused on her pedagogy and highlighted the importance of having students question their own answers:

> So as tricky as this conversation was, I was really happy with it, because I did get them to, you know, question why. I mean, that's, that's really hard to pin. So I was happy to get it. You know, again, it's one of those cases where if the answer itself matters less than the thinking, the fact that he was thinking about it [the reasoning], it was a bigger win.

Figure 7.23 Distribution of Amna's attention in the pre- and post-PD discussion



After the PD, Amna increased the frequency of her noticing to a total number of 29, among which pedagogy, student science ideas, classroom climate, and student characteristics had the highest frequency (Figure 7.23). In the following moment, Amna described her attention on students' science ideas (i.e., echo as sound going back and forth) and lived experience (i.e., their vocabulary of wobbling to describe vibration) as well as her concern for classroom equity (i.e., that she did not address one of the students' questions in the moment):

> I really liked that they didn't know the word echo yet. But they were talking about the sound going in and coming back. I like that. I also really like that they describe the vibration as wobbling. It's nice to see a child's vocabulary and how they experience the same thing. But then I was sad that I heard one of the students asking like, Ma'am Amna, I have a question. And I just felt so bad. I didn't. I didn't ask her what the question was. I wish I have asked.

In summary, there is an increase in all three teachers' targets of attention both in terms of frequency and diversity, indicating the deployment of flexible attention to capture various dimensions in a multifaceted classroom. These findings support the emergence of the mediating process, deploying flexible attention. In the following section, I discuss the theoretical conjecture of how flexible attention leads to teachers' contingent responsiveness.

7.5.4 Theoretical Conjecture 3: [Deploy flexible attention] → [CR]

The theoretical conjecture hypothesises that teachers' flexible attention can lead to CR. Teachers cannot respond to something if they do not pay attention to it first. In other words, teachers' attention partly defines what they will respond to and how they will respond. In the retrospective interview, each teacher described how their attention had shaped their response to the student.

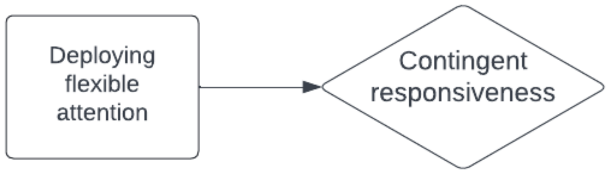
For instance, one of Fatima's primary focuses on attention in the post-PD discussion surrounded student characteristics and classroom equity. In the retrospective interview, she expressed the challenge of supporting a diverse group of learners with various needs to engage in productive talk together. She noted that:

> Most of this video is reminding me of the struggles that we face when one child is answering really well, but other children are so bored, and they don't really want to listen because not a lot of children are engaged at the same time.

As a result of her attention to student characteristics and equity, in the discussion, Fatima tried to strike a balance between being caring to the individual students and engaging the whole class to advance their thinking together. Therefore, she kept circling back to the original question about observations in the field trip to ensure equitable learning opportunities for all students. Thus, Fatima's response pattern is coherent with what she paid attention to in the discussion. Similarly, in the post-PD discussion, Minahil focused on students' various lived experiences about recycling and reusing, which aligned with her response pattern of widening and maintaining the dialogic space. Amna especially paid attention to students' science ideas in the post-PD discussion, leading her to press and challenge their science ideas on multiple occasions, which is also reflected in her response pattern of maintaining and deepening the dialogic space.

In summary, the coherence between teachers' response pattern and their attention provide evidence to support the theoretical conjecture that deploying flexible attention can lead to teachers' CR. Figure 7.24 shows the theoretical conjecture and mapping of developing flexible attention to CR.

Figure 7.24 Theoretical conjecture 3: [Deploy flexible attention] → [CR]



7.5.5 Design conjecture 4: [MRS] & [Collective reflection] → [Develop flexible attention]

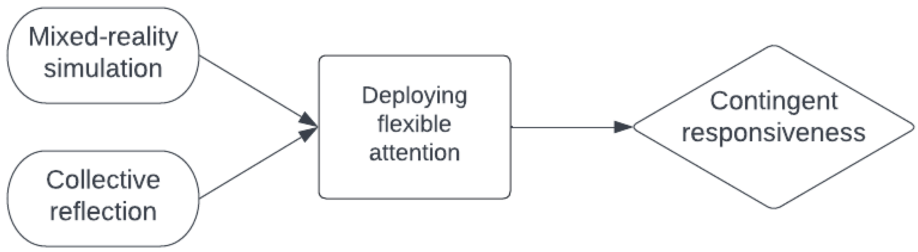
Design conjecture 4 hypothesises that embedding various dimensions of the classroom in the simulation followed by teachers' collective reflection can support teachers to develop flexible attention. For instance, in Simulation 2, the host avatar prompted teachers to identify various dimensions of the classroom discussion. All three teachers were able to successful identify various dimensions of the discussion.

Minahil recognised student science ideas (e.g., student knowledge about evaporation), lived experience (e.g., Ava's experience that her lake does not disappear because of evaporation), and equity issues (e.g., her difficulty in bringing Savannah to the discussion). As the observing teacher in this round, Fatima noticed the variety of student ideas and the challenge in coordinating and building on all the student ideas. Amna also noticed Dev's science ideas and his question about where the water goes during evaporation as well as classroom equity:

> Dev mentioned vapour, and then he had a deeper question that event evaporated, where did the water go? I liked that. That's a thought that he brought up. I do like that everyone did contribute. But I think with Savannah, I always wonder, could I have had her speak more? But I think any interaction with her, I'm happy.

Teachers' successful identification of various dimensions in the simulated class in the collective reflection provides some evidence that MRS and collective reflection can support teachers to develop flexible attention. Figure 7.25 summarises the design conjectures and theoretical conjectures related to deploying flexible attention.

Figure 7.25 Design and theoretical conjectures related to developing flexible attention



7.6 Engaging in knowledge-based reasoning

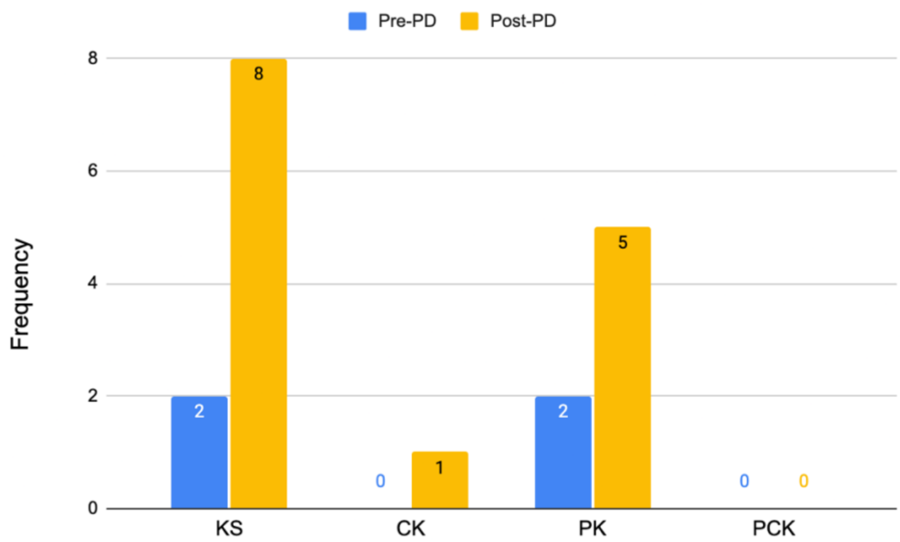
Teachers have a range of knowledge about their students, the subject, and pedagogy, which Schoenfeld (2010) refers to as intellectual resources, from which they draw on to make sense of their noticing. The process of making use of one's knowledge and experiences to make sense of what is observed is called knowledge-based reasoning (van Es & Sherin, 2002). Drawing on Shulman's (1987) framework of teacher knowledge, five types of knowledge were identified in teacher's retrospective interview: 1) knowledge about students (KS), 2) content knowledge (CK), 3) pedagogical knowledge (PK), 4) pedagogical content knowledge (PCK), and 5) knowledge about the educational context (KC). Because KC was not part of the PD, only KS, CK, PK, and PCK were included in the coding of teachers' retrospective interviews. I first segmented teachers' retrospective interviews based on the moments they chose to pause the video recording. Teachers' interpretation of what they noticed in the moment was systematically coded based on the presence or absence of the type of knowledge. 30% of the dataset was independently coded by another doctoral researcher and myself. Inter-rater reliability is calculated using Cohen's Kappa. As shown in Table 7.7, substantial agreements were reached for all codes. The full coding scheme can be found in Appendix 5.

Table 7.7 Inter-rater reliability for knowledge-based reasoning

Code	Cohen's Kappa
Knowledge about students (KS)	0.827
Content knowledge (CK)	0.646
Pedagogical knowledge (PK)	0.697
Pedagogical content knowledge (PCK)	0.777

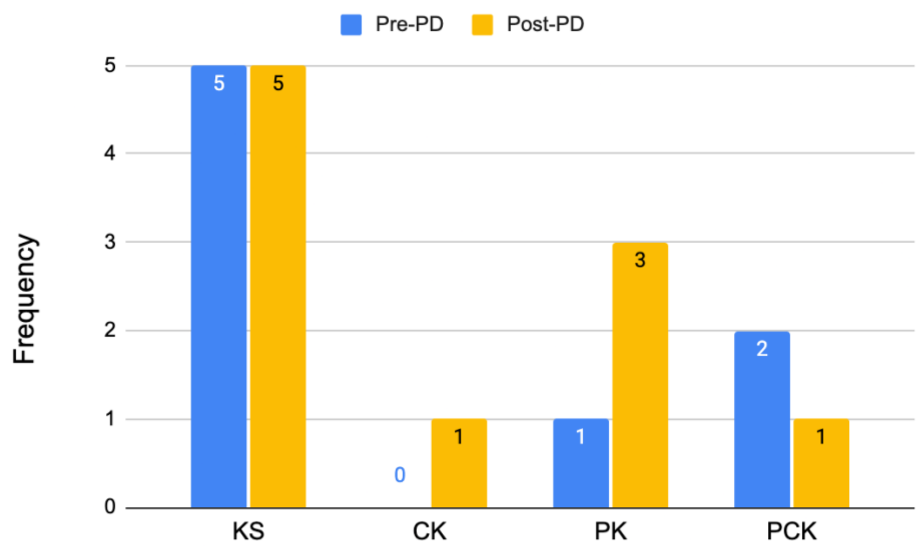
There is evidence for the emergence of knowledge-based reasoning as a mediating process. In the retrospective interview, teachers engaged in knowledge-based reasoning more often and drew on more varied sources of knowledge. Fatima showed an increase in the frequency of knowledge-based reasoning after the PD. She especially used KS and PCK to make sense of her noticing (see Figure 7.26).

Figure 7.26 Fatima's knowledge-based reasoning before and after the PD



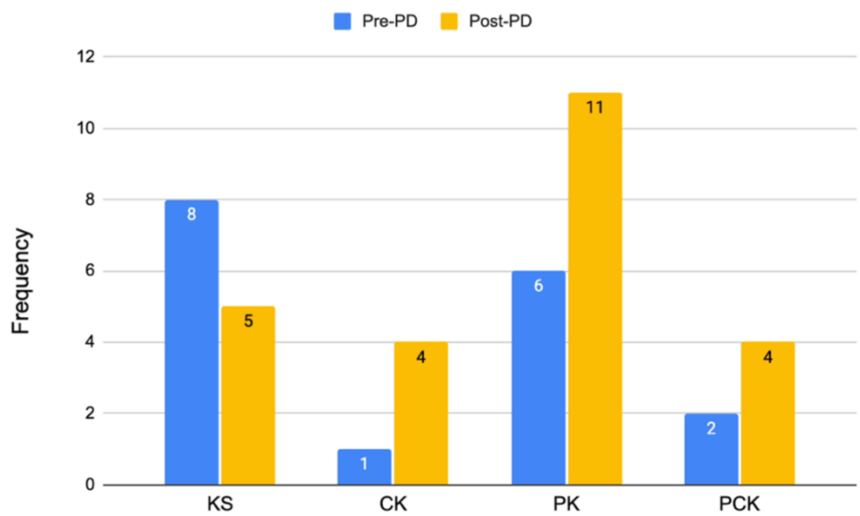
Before the PD, Minahil primarily relied on KS to make sense of her noticing. After the PD, she also drew on PK in addition to KS (Figure 7.27).

Figure 7.27 Minahil's knowledge-based reasoning before and after the PD



Before the PD, Amna most often drew on PK and KS to make sense of her noticing. After the PD, she expanded her repertoire of knowledge for reasoning in terms of PK, CK, and PCK.

Figure 7.28 Amna's knowledge-based reasoning before and after the PD



In summary, there is evidence for the increase in the frequency of knowledge-based reasoning and diversity of knowledge teachers drew on after the PD, especially in KS and PK. In general, CK and PCK have relatively lower frequencies compared to KS and PK.

7.6.1 Theoretical conjecture 4: [Knowledge-based reasoning] → [CR]

Theoretical conjecture 4 hypothesises that teachers' knowledge-based reasoning can lead to CR. There is evidence in teachers' retrospective interviews of how their knowledge-based reasoning shaped their response to promote sense-making. I present one example from Minahil's post-PD discussion and her retrospective interview to illustrate how her knowledge-based reasoning allowed her to contingently respond to student ideas in real time to promote sense-making in the science discussion.

During the retrospective interview, Minahil attended to one interesting phenomenon in her science discussion that students often brought Islamic studies to science discussion:

> So you know when we ask our children a question that why is a particular thing like that? Most of our children, you know, answer because Allah made it like, and that is their ultimate answer. So and when they don't know technical answer to a question or the logical answer to the question, you know, they say Allah made it.

Minahil drew on her knowledge about her students, her content knowledge about science (i.e., science focuses on logic and reasoning), her pedagogical knowledge (i.e., children's developmental stage), knowledge about the context (i.e., teaching of Islamic studies at the school) as well as her experience as a parent (i.e., how she explained the relationship between science and religion for her own children) to make sense of her observation:

> Yeah, for me, like as a mother, I have always told my children that you know, I am a new teacher, I started working just a year ago with little children. I previously used to teach the older children my own subject that I have studied. But this is my first experience with little children. So when my children were at that age, I always tried to connect everything with science, like I always told them that there is nothing that is illogical in this world. You know, of course, I introduced Allah and God, and you know, everything is created by him, but I always told them that there is always there is a science behind everything, like nothing is without purpose. So I try to incorporate that here in my class.

During the discussion about lake pollution and the environment, students brought up Allah several times as shown in the following excerpts in Tables 7.8, 7.9, and 7.10. Minahil always acknowledged students' ideas first followed by a redirection towards scientific practice to promote sense-making. For example, in the excerpt in Table 7.8, Minahil acknowledged students' ideas that Allah created the environment, and then redirected their attention to their observation during the field trip.

Table 7.8 Excerpt of Minahil's post-PD discussion (Part 1)

Turn	Speaker	Utterance
31	Maham	This is not our environment. It is everybody's environment. Allah created it.
32	Minahil	Yes, Allah has created this environment, and it is everybody's environment. Faria, what did we find near the lake? What did you see?

Similarly, in Turn 38 in Table 7.9, Minahil acknowledged the importance of taking care of the environment and then redirected students' attention to reason about people littering in the lake.

Table 7.9 Excerpt of Minahil's post-PD discussion (Part 2)

Turn	Speaker	Utterance
36	Minahil	So why do people trash in the lake? Yes, Faria, what do you think?
37	Faria	[inaudible]. With people throwing trash everywhere, Allah will be sad.
38	Minahil	Yes Exactly. We should take care of the environment. What do you think Anam?

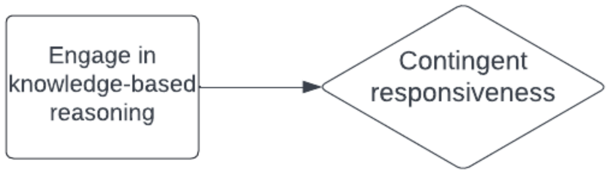
Table 7.10 Excerpt of Minahil's post-PD discussion (Part 3)

Turn	Speaker	Utterance
60	Ayesha	Actually, if we litter, Allah would not like us. If we litter, the police officer will come. Allah will put something in their mind.
61	Minahil	Exactly. So actually Allah like cleanliness so we should not litter…so what should we do? one thing that you all say that we should put the trash in the bin. What else can we do with the trash? Yes one by one. Yes, Hafsa?

In Turn 61 in Table 7.10, Minahil acknowledged student ideas about Allah's appreciation of cleanliness and then redirected their attention to brainstorm potential solutions to lake pollution.

In this synopsis of Minahil's knowledge-based reasoning and her corresponding response to her students, it is evident that engaging knowledge-based reasoning can foster teachers' CR. Figure 7.29 shows the mapping of engaging in knowledge-based reasoning as a mediating process to CR.

Figure 7.29 Theoretical conjecture 4: [Knowledge-based reasoning] → [CR]



7.6.2 Design conjecture 5: [MRS] & [Collective reflection] → [Knowledge-based reasoning]

Design conjecture 5 hypothesises that collective reflection during the simulation can foster teachers' knowledge-based reasoning. During the PD, teachers were prompted to engage in knowledge-based reasoning with their co-teachers immediately after a round of simulation (in Simulation 3 and 4). The host avatar encouraged teachers to reflect on how they responded to promote sense-making, why they chose to respond in a certain way, and how it could be improved/respond differently.

There is evidence of teachers engaging in knowledge-based reasoning during the collective reflection in the simulation. For instance, Minahil noticed Dev's science idea, and she used CK and PK she learned from PD to reflect on a moment where she thought she promoted student sense-making:

> So initially, when I started with Dev, since he had the idea of evaporation, he came up with only one idea, and that was evaporation. And that too, he wasn't very sure why and how water evaporates. Like he knew that the water evaporates, but he did not have any evidence. So I think at that time, I challenged his idea and passed it on to Jasmine and Ethan. So because they also worked on the concept of evaporation along with other two concepts, that was the time I felt I actually move the discussion forward.

Amna made use of her PCK about scientific reasoning and relationship to reflect on how she moved student thinking forward:

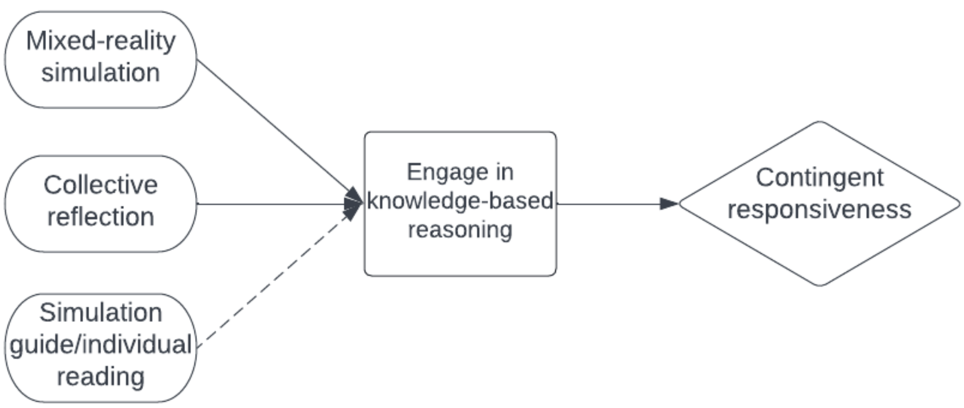
> There are two things I tried to do multiple times, it was asking them to draw connections in their own reasoning, and also look for suggestions and their peers' answers, sort of try to see if there's anything they may have missed, or anything that's giving them any new ideas on something, [that is] I was trying to do.

In summary, the evidence of teachers engaging in knowledge-based reasoning during the collective reflection in the simulation provided support to design conjecture 5.

7.6.3 Design conjecture 6: [Simulation guide/individual reading] →[Knowledge-based reasoning]

Design conjecture 6 hypothesises that the simulation guide that contains CK, PK, and PCK can support teachers to engage in knowledge-based reasoning. In the simulation feedback, some teachers mentioned the simulation guide as a helpful design feature for their simulation. However, teachers did not specifically mention how they made use of the materials in the simulation guide in knowledge-based reasoning. In the collective reflection during the simulation, though there is evidence of teachers using CK, PK, and PCK in their reflection, there is no specific reference to the simulation guide during the reflection. Therefore, there is not enough empirical evidence to support this design conjecture, which is illustrated with a dotted line in the conjecture map (see Figure 7.30).

Figure 7.30 Design and theoretical conjectures related to engage in knowledge-based reasoning



7.7 Experiencing metaphoric resonance

Metaphoric resonance concerns the recognition of structural resemblances that lead to analogical thinking and reasoning (Mason & Davis, 2013). According to Mason (2002), elements in the structure of the current situation can resonate with a metaphor or structure of previous experience, bringing associated thoughts and awareness to mind. This PD programme leveraged metaphoric resonance to cue teachers to specific moments in the PD and simulations to contingently respond to student ideas, which could require them to diverge from their usual discourse pattern. For example, throughout the PD, there were case studies and simulation scenarios that shared a structural resemblance to the teachers' own teaching experiences. There was evidence in the post-PD discussion that teachers experienced metaphoric resonance as a mediating process, which led them to respond to students who diverged from their usual discourse pattern (Theoretical conjecture 5).

The following synopsis in 7.7.1 from Minahil's post-PD retrospective illustrates how she experienced metaphoric resonance in the midst of a discussion, which led her to diverge from her usual response pattern.

7.7.1 Theoretical conjecture 5: [Experiencing metaphoric resonance] → [CR]

Theoretical conjecture 5 hypothesises that experiencing metaphoric resonance can lead teachers to contingently respond to student talk that promotes sense-making and classroom equity, which sometimes require them to diverge from their usual discourse pattern.

Minahil accounted during the post-PD interview a moment in her classroom, where she experienced metaphoric resonance. She was leading a consolidation discussion after a field trip to a local lake. The students observed a lot of trash and pollution in the lake during their field trip, and she then pressed children to reason about "Why people throw trash". One of the students, Maham, said that people throw trash because people do not have an education. During the post-PD interview, Minahil paused the video recording here as a noteworthy moment and described her initial surprise at the Maham's comment:

> So I was a little shocked at the answer. Because she [Maham], she's so small, and she related it to the education that says people you know, in our country, a lot of people are not educated. So they don't know that it's not good to throw trash.

Minahil recognised a resemblance of the current situation to one of the case studies they discussed in the workshop:

> So here during the class, this just clicked into my mind the scenario that we discussed in our workshop, that the teacher was asking the children what plants need to grow, and the children were saying sunlight and soil and all the important things that plants need to grow, but one of the children said that plant needs earthworms to grow. Now, this just clicked in my mind at this particular time.

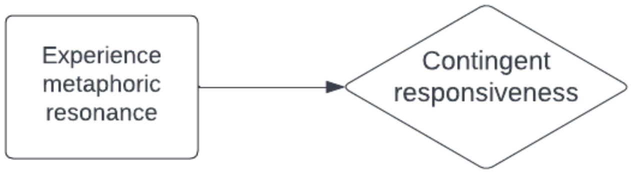
The case study that Minahil was referring to was about a teacher shutting down students' sense-making space when she felt the student's idea (i.e., plants need earthworms to grow) did not adhere to her instructional plan and the curriculum. As a result, students did not get the chance to delve deeper into the complexity of an ecosystem and the role that each organism (e.g., earthworm) plays in supporting the growth of the plants. Minahil experienced metaphoric resonance by recognising the structural resemblance between Maham's comment about education and the earthworm comment in the case study. In both cases, teacher were surprised with ideas of the students because they did not necessarily align with the teacher's original instructional goal. Unlike the teacher in the case study who shied away from the student's idea, Minahil decided to pursue Maham's idea by opening up the sense-making space. She first revoiced Maham's idea to the whole class and then asked Maham to say more. Together the class talked about whether we need education to know not to litter and take care of the environment, which lasted 20 turns of talk.

During the interview, Minahil described how this metaphoric resonance led her to diverge from her usual response pattern:

> I didn't know that the child is going to give me that answer [about education], which make me think of the scenario that I had studied, you know. And so it just clicked with me. And I then applied it there. And then, since I knew that, you know, this is, this is a thing that I can do, then I did it. Otherwise, I wouldn't have done [taking up student query]. If I hadn't taken the workshop, I wouldn't have done that.

Minahil’s account shows that she experienced metaphoric resonance at the moment that she recognised the situation she was facing bore a structural resemblance to a case study that she had encountered during the workshop. Minahil’s account provided evidence for the emergence of metaphoric resonance as well as how it can lead to teachers contingently responding to student ideas, especially when it requires them to diverge from their usual discourse pattern. Figure 7.31 shows the mapping of experiencing metaphoric resonance as a mediating process to CR.

Figure 7.31 Theoretical conjecture 5: [Experience metaphoric resonance] →[CR]



7.7.2 Design conjecture 7: [Case studies]→ [Experience metaphoric resonance]

Design conjecture 7 hypothesises that studying a variety of cases allows teachers to experience metaphoric resonance. Minahil’s account above about how the case study clicked into her mind in the midst of her leading a discussion in her class is one piece of evidence for design conjecture 7.

Similarly, Amna described moments when she recognised a popcorn discussion (a case study in Workshop 2) and sense-making discussion (a case study in Workshop 3) in the retrospective interview:

> But at other times, if, for example, we, if we have a seemingly unproductive class, in the sense where we didn't reach the [planned] conclusion. We didn't get to the point we wanted, we'd be like, you know, so okay, this was the sense-making. And I remember when that was once or twice, we did realise, okay, so this is what a popcorn discussion is.

These two examples provide evidence for Design conjecture 7 that being exposed to a variety of cases in the classroom can support teachers to experience metaphoric resonance.

7.7.3 Design conjecture 8: [MRS] → [Experience metaphoric resonance]

Design conjecture 8 hypothesises that teachers' experience with a variety of scenarios in the mixed-reality simulation can help them to experience metaphoric resonance. Amna described a moment in her post-PD discussion, when she experienced metaphoric resonance, recognising the resemblance between the current situation and what she experienced in the simulation. During Amna's post-PD discussion, one of the students Bilal, asked "what is a molecule made of" when the class was discussing sound and vibration. Amna underlined this moment and said:

> I remember when Bilal asked this question, I was thinking back to our simulation, where [the avatar] instantly you know [went to a different direction] when they heard something that only shares one word in common. Throughout a lot of our discussions, we've been grateful for the simulation where we immediately connect back to our personas of the avatars in the simulation.

She further described how she was able to connect the case pupils represented by the avatar to her students:

> Yeah. So sometimes we, we've actually taken literal sort of references from the avatars. You know, so a student will say something, and we will be like, okay, you know, Ethan [an avatar], we will be like, okay. Yeah. Ava [an avatar]. And then that's, and that's so important. Because it's not as much as stereotyping, it is understanding a persona…you don't feel as frustrated anymore [when they behave a certain way] because you now understand their motives and their driving forces.

Minahil talked about how she connected the case pupils in the simulation to her own class:

> Because we did the simulation, we could relate it in our class. Savannah [an avatar], who was not participating, you know, we could see that in our class as well. You know, the other way around, we saw our own students in Savannah, and then, you know, we see that we have children in our class who are not participating. So when I was conducting the class, I was thinking that there are some children who are not participating, so I should try to help them participate.

The connections teachers made between the simulation and their own class provide evidence for Design conjecture 8 that the exposure to a variety of scenarios in the mixed-reality simulation allows them to experience metaphoric resonance.

7.7.4 Design conjecture 9: [Talk moves labelled by dialogic functions] → [Experience metaphoric resonance]

Design conjecture 9 hypothesises that labelling talk moves by their dialogic functions can help teachers to experience metaphoric resonance. Mason (2002) suggested the strategy of labelling complex ideas to trigger metaphoric resonance, i.e., to have names for complex ideas. He noted that if we do not have a label for something, it escapes our notice. Labels could be words associated with a rich collection of different accounts and alternative strategies. According to Mason, labels are useful devices to awake the teachers during the course of action, helping to present teachers with alternatives in the moment rather than in retrospect. In the PD, talk moves were labelled according to their dialogic functions, i.e., opening, widening, deepening, maintaining, shaping, and closing. There is evidence that teachers adopted these labels as part of their vocabulary to reason about their responses to students.

Fatima accounted for the usefulness of labelling complex ideas:

> Talk moves have come become kind of part of our vocabulary, widening the discussion or, you know, shutting down the discussion. So that really helped because sometimes you are doing something, but you don't really know that it has a specific meaning or name attached to it. So when you actually know what things are, you start incorporating them consciously. And you can also tell, for example, that you are able to relate to things better, you're able to relate to your own teaching better, and you are able to pinpoint your own mistakes better. So where we were at the start of the workshop, there's a huge difference to where we are standing now.

Similarly, Amna also mentioned the importance of labelling, which helped her to think more clearly and connect to other teaching strategies:

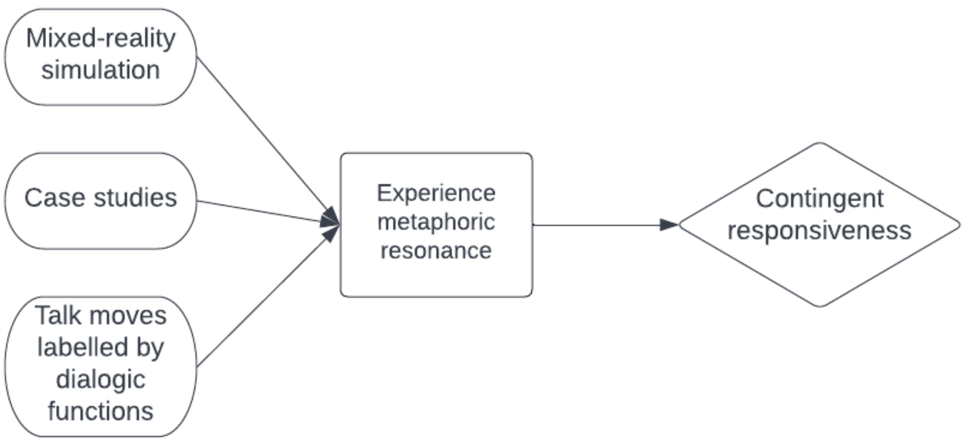
> A lot of things you taught us, we were doing them subconsciously. But having them formalised like this helps us think more clearly. It's helped us in our lesson planning, and now we have, you know, we've been doing the routines, the projects zero routines. And now, I think the reason it's been easier for us to connect to the routines is because we're familiar with the sense making space. So now, it's much more natural for us to pick a suitable routine.

Minahil adopted the vocabulary of dialogic functions to reason about her pedagogical decision and reflect on how she can improve:

> I also realised later when I watched my video, that although I tried to widen the sensemaking space at one place, I later realised that I also funnelled my discussion, in a certain direction telling them that see, no, it really doesn't have to do anything with education. Although I tried to be really on point and try to maintain and widen the sense-making space, then I realised that oh, I also made a mistake that I just funnelled the answer in a certain direction.

In summary, labelling talk moves in accord with their dialogic functions can help teachers to recognise structural resemblance among various situations and types of discussion, i.e., experience metaphoric resonance. Figure 7.32 summarises the design conjectures and theoretical conjectures related to experiencing metaphoric resonance.

Figure 7.32 Design and theoretical conjectures related to experiencing metaphoric resonance



7.8 Overall supporting features in the PD

All the design features mentioned above aimed to foster teachers' contingent responsiveness. There were also features in PD that were not directly linked to CR, but nonetheless played an important role in facilitating teachers' learning.

7.8.1 A supportive community of practice

The first supporting feature is a supportive community of practice, which was taken into account in the design of the PD. A number of activities were designed to create a supportive community of practice at the start of the PD, such as the warm-up activity at the beginning of each workshop and ground rules in the breakout rooms. These are exogenous design features, designed to be implemented in the learning environment. During the interviews with teachers, I noticed a small community of practice among Fatima, Minahil and Amna, that is endogenous to the learning context, i.e., it organically evolved rather than exogenously designed.

Fatima described how they gave each other feedback in their daily practice:

> We have three teachers right now for this class. So we find a good balance. We are open to when the other person tells us, this is something that we could have done differently. So how about we do this in that class. That helps.

Amna also mentioned how they connect their practice to the PD and encourage each other:

> I think because of all the teachers, I think, me, Ma'am Fatima and Ma'am Minahil, we've been with you from the very start, we've experienced the whole thing. And our conversations about the classrooms have changed, and, and if there is a moment, if one of the teachers is feeling discouraged or frustrated, we are able to connect it back to what we've learned. And then sort of, you know, pacify each other that look, this is part of the process. And that really helps, you know, because before that, we were getting discouraged a lot faster.

7.8.2 A mindful facilitator

Another supporting feature in the PD was a mindful facilitator. A strong bond and trusting relationship formed between the teachers and researcher/facilitator. Teachers expressed their appreciation to the researcher/facilitator either in the retrospective interview or the anonymous feedback. The trusting relationship between Amna and the researcher was evident when she decided to share a video recording of her class that she was not completely satisfied with. When talking about the context of the discussion in her video, Amna said:

> The recording I sent was possibly as candid as can be. Then I was watching it again, I was thinking, Should I record it again? Should I send a different lesson? It was, you know, one of those days where we combined both our sections (lessons) because there weren't enough students in both of them. So they were all a little bit distracted.

She is comfortable in sharing the video as she said:

> One of the reasons I was so comfortable sending such a candid lesson is because I knew that you would understand and it's important for you and your research to also see how, how it's being implemented.

Amna saw the interview with the researcher as an opportunity for learning:

> So I really appreciate that. You know, we were recording our lesson. It actually helps so much. You actually see what the students see in that time.

Amna's attitude towards the interview as a learning opportunity was also voiced by Fatima:

> I think Amna had a conversation with you. Her class was not going as planned at all. But she said I wanted to show this video to Lydia because we might get some ideas [to improve our teaching].

Fatima appreciated the encouragement from the researcher:

> Thank you because you are always very encouraging and that really helped because it kind of gave us a confidence boost.

Minahil appreciated the fact that the researcher was accommodating to the teachers and their needs:

> And it was actually very lovely, lovely knowing you and you've already always been so accommodating. Like, I think we bothered you a lot. Although you have so much to do, but you know, we kept changing you know, there were times when we I asked you to reschedule the meeting or you know, when we have a hard day, we keep asking you that, you know, change it or can we do it later. And thank you because you made it so easy for us. Like you didn't you

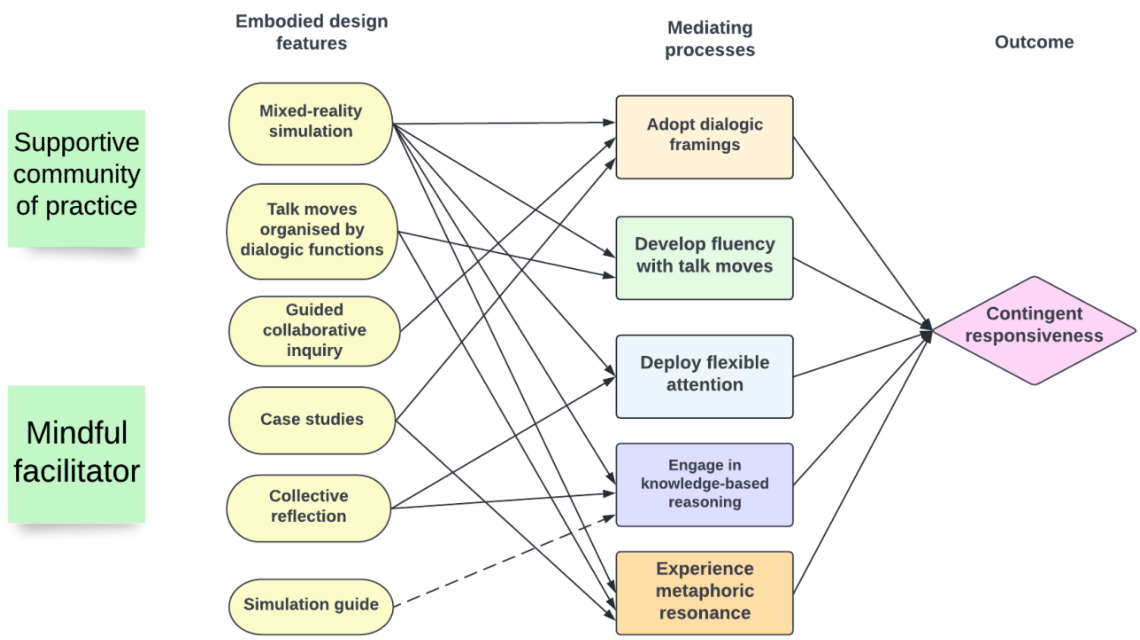
never actually gave us any kind of pressure. You were accommodating and made all of us very comfortable with the whole workshop.

7.9 Summary of results for RQ2

This chapter answered Research question 2, how the PD works, by systematically mapping design features to mediating processes, to learning outcomes, which is summarised as a conjecture map in Figure 7.33. In the conjecture map, solid lines represent conjectures that are observed and supported with empirical evidence, whereas the design conjecture represented by the dotted line lacks empirical support.

The mechanisms of the PD was revealed in terms of design conjectures (how the mediating process emerges in relation to design features) and theoretical conjectures (how the mediating process gives rise to the outcome). The results showed five mechanisms working in synergy for teachers' contingent responsiveness: 1) adopt dialogic framings, 2) develop fluency with talk moves, 3) deploy flexible attention, 4) engage in knowledge-based reasoning, and 5) experience metaphoric resonance. These five mechanisms were produced by a combination of design features: 1) mixed-reality simulation, 2) talk moves organised by dialogic functions, 3) guided collaborative inquiry, 4) case studies, 5) collective reflection.The overall supporting features (i.e., a supportive community of practice and a mindful facilitator) created an amicable and safe learning environment for learning to take place.

Figure 7.33 Final conjecture map



The dotted line represents hypothesised relations that were not observed in this study.

Chapter 8 Discussion

The aim of this DBR study was twofold: 1) to design an effective PD programme to foster teachers' CR and 2) to understand the mechanism of the PD programme that allows teachers to develop CR. The effectiveness of the PD is demonstrated by the shift in teachers' response patterns after the PD (see Chapter 6), and the mechanism of the PD is revealed in terms of theoretical and design conjectures (see Chapter 7). In this chapter, I discuss the implications of these findings and their limitations. I also reflect on the role of technology in this study, the guiding principles to use MRS for PD, the design context, as well as the affordances of the DBR as a method for doctoral studies.

8.1 The Chiasm approach to assessing CR

The results in Chapter 6 show that the PD effectively supports teachers in developing the situation-dependent skill to respond to the dynamic student talk in the moment by widening, deepening, maintaining, and shaping the dialogic space. All three teachers changed their response patterns after the PD. Using a chiasm approach, this study captured teachers' responsiveness from both the outside and inside, juxtaposing the researcher's analysis with teachers' own accounts in the retrospective interview.

From the outside perspective, ENA showed significant differences in the response patterns of the three teachers before and after the PD, both visually and statistically. Overall, before the PD, teachers' responses generally focused on initiate-feedback or only eliciting student ideas without student collective sense-making. After the PD, teachers adopted dialogic framings of science discussions and focused on widening, deepening, and maintaining the dialogic space. The quantitative analysis of ENA was triangulated with the qualitative discourse data, closing the interpretive loop by returning to the original qualitative data to make sense of the response pattern revealed in ENA to ensure the validity of the results (Shaffer, 2017). From the inside perspective, teachers accounted for their own experience and interpretation of the discussion in the retrospective interview, which not only enriched but also augmented the outside view of the researcher.

Wegerif (2020) argues that the perspective of teachers moving from inside-out and the view of the researcher that is trying to define and locate that experience from the outside in, are fundamentally incommensurable. The chiasm approach proposes to bring the outside and inside view together, to allow inter-animation, and to gain new insights and meaning without ever fully integrating them into a single vision (Wegerif et al., 2020). Unlike triangulation, a chiasm approach does not seek to reduce the researcher's view and teacher's view into a single gaze, but rather hold both in generative tension, to inter-animate each other. As discussed in Chapter 2, the assessment of teacher responsiveness has been dominated by a monologic stance, meaning that researchers define responsiveness in advance and then try to locate it in teachers' practice using a predetermined observational rubric and a set of indicators (e.g.. Lineback, 2015; Pierson, 2008). Such an approach is conceptually problematic since it contradicts the essence of responsiveness, which has to be contingent on the ever-changing needs of the situation and depends on teachers' attention, interpretation, and framing of the situation (See Richards et al., 2020; Robertson et al., 2016).

This study illustrated the fruitfulness of a chiasm approach to capture the fleeting notion of responsiveness by juxtaposing the researcher's view from the outside in with the teachers' perspectives from the inside out, augmenting and inter-animating both views. Teachers' account of their in-moment pedagogical decision-making allowed researchers to see things that were not observable in the video, such as characteristics of the students, teachers' pedagogical reasoning, and the educational contexts. For instance, during the retrospective interview, Fatima explained the diverse needs of her learners in the classroom, which helped the researcher to understand why she kept circling back to her original question during the discussion . Minahil explained her pedagogical decision of not calling on one student to give the student (who is new to the school) time to warm up to the envrioment. Without the teachers' inside view, the outside view could interpret it as Minahil not attending to class equity. Similarly, Amna underlined the unusual situation of a combined class (i.e., she had twice as many students in the post-PD discussion). Without her inside view of her classroom context, the outside view could easily see the class as disorganised. Therefore, teachers' views in the retrospective interview allowed me to see their classroom through their eyes, which helped me to make more accurate interpretations. At the same time, the researcher's view from the outside also augmented and shed light on areas that teachers might not have seen. For example, the visualisations created by ENA provided a bird's-eye view of teachers' discourse patterns, informing teachers about their practice, and supporting their reflection to improve their practice.
In a recent systematic review about technology use for teacher professional development in low and middle-income countries (LMICs), Hennessy et al. (2022) found that most studies relied on self-reporting to measure changes in teacher knowledge and practice, a method with well-known

limitations in terms of validity. The chiasm approach has the affordances to address this gap by capturing changes in teachers' practice via observation (in-person/video) followed by retrospective interviews with teachers about this specific episode of the classroom (instead of a general decontextualised self-report about their learning in the PD). The chiasm approach is dialogic in nature. By seeing things through the eyes of one another, it reinforces the equitable and reciprocal contribution from the teachers and researchers as well as mutual trust. The establishment of a trusting relationship was best seen in this study when Amna decided to share a post-PD video that she was not very satisfied with (see Section 7.8.2). According to her, she wanted the researcher's view and suggestions so that she could improve her practice. It was apparent that Amna saw the post-PD discussion and interviews as a genuine opportunity for learning rather than an evaluation of her practice.

In summary, this study illustrated the affordances of using a chiasm approach to capture teachers' CR, creating an augmented view of the data, and building trusting dialogic relations between teachers and researchers to learn together to generate knowledge and impact.

8.2 An emerging learning theory of CR

A preliminary learning theory of CR emerged in this study in terms of five theoretical conjectures:

1) adopting dialogic framings,
2) developing fluency with talk moves,
3) deploying flexible attention,
4) engaging in knowledge-based reasoning,
5) experiencing metaphoric resonance.

The implications of each mechanism are elaborated below.

8.2.1 Adopting dialogic framings

This study found that all three teachers adopted dialogic framings of science discussions after the PD. Both Fatima and Minahil shifted from framing discussions as interactive lectures to scientific consolidation discussions after the PD. Amna's pre-PD discussion was a mix of a popcorn discussion and lecture, and she framed her post-PD discussion as an elicitation discussion. The adoption of dialogic framing fostered teachers' CR, evident in the drastic shift in teachers' response patterns in Simulation 2, in which the task was framed as an elicitation discussion. For instance, Fatima's pre-PD response focused on initiate and feedback, whereas her response pattern in Simulation 2 drastically shifted towards maintain-widen. Minahil's pre-PD response focused on initiate-feedback, whereas her response pattern in Simulation 2 moved towards maintain-widen and maintain-feedback. The results in Section 7.3 showed that teachers' response patterns were coherent with the framing of an elicitation discussion—Fatima, Minahil, and Amna all focused on widening and maintaining the dialogic space to uncover a variety of student ideas.

Such a drastic shift in teacher's response patterns after adopting a dialogic framing concurs with Russ and Luna's (2013) finding that teachers' attention and response are partly driven by their localised framing, i.e., a teacher's sense of what is going on in interaction or sense of what activity is being engaged in. For example, when teachers framed their discussions as interactive lectures, they focused on initiating questions and providing students with feedback. On the other hand, Simulation 2 was framed as an elicitation discussion, and as a result, their response pattern shifted towards maintaining and widening to uncover a variety of student ideas. Teachers' drastic shift in their response pattern after adopting a dialogic framing challenges the stage-based linear development of responsiveness, from low to medium to high (e.g., Empson & Jacobs, 2008) because it is unplausible that teachers' could largely increase their CR only after two workshops and one orientation simulation. This study showed teachers' non-linear progression in CR. In fact, in this case, teachers' CR was partly activated/deactivated depending on their framing of the discussion. This finding aligns with Robertson et al. (2016), who illustrated that responsiveness is located in the complex interplay among the actions, content and goals. This finding has significant practical implications for future PD initiatives of dialogic teaching—a macro-level shift in framing can result in a micro-level shift in teachers' response patterns. Therefore, to support teachers in changing their discourse patterns, PD can focus on helping teachers to recognise and adopt dialogic framings.

8.2.2 Developing fluency with talk moves

This study found that not only did teachers apply talk moves more frequently, but they also expanded the repertoire of talk moves. Taking into account all of the talk moves applied throughout the PD, three teachers displayed different preferences with their application of talk moves. Fatima's top three talk moves were add-on/build-on, revoice/invite-revoice, and open-ended questions. Minahil used revoice, add-on/build-on, and press the most often. Amna had a more even distribution of talk moves among add-on/build-on, press, say more, opened-ended questions, and synthesise. Notably, synthesis was among the talk moves that were least frequently used.

The low frequency of synthesis as a talk move concurs with earlier findings on the low occurrence of coordination codes that are about synthesis and connecting of ideas (e.g., Howe et al., 2019; Vrikki et al., 2019). According to Vrikki et al. (2019), the low occurrence could partly be due to the fact that these moves are applied rarely compared to other moves by the nature of coordination, occurring only used after a sustained exchange of ideas (Hennessy, Rojas-Drummond, et al., 2016) as well as the challenge of keeping track of multiple ideas from students. In this study, Fatima and Minahil rarely used the synthesis move, which could be future areas of investigation and focus of PD. Another interesting finding that differs from earlier studies was teachers' frequent application of the talk move 'revoice/invite revoice'. Chen et al. (2020) found that teachers did not use more 'revoice', 'restate', and 'explain other' after the PD and they suggested a possible developmental sequence in the adoption of productive talk moves. This study found that revoice/invite revoice is one of teachers' top talk moves. According to the teachers, the reason is that their learners are very young, and frequent revoicing helps students to be on the same page of the discussion. It is important to note that Chen et al.'s (2020) research context was secondary mathematic teachers working with 6th/7th grade, whereas the teachers in this study were first-grade teachers. This study suggests that the choice of talk moves might also have to do with the context of the class, such as the age of the learners. It is possible that talk moves might occur more naturally to a younger audience than to an older one. The variation in the adoption of talk moves is an interesting area of future research.

8.2.3 Deploying flexible attention

Teachers cannot respond to something they do not attend to; thus, it is crucial for teachers to deploy flexible attention to the multifaceted classroom. In Chapter 4, I argued that teachers' attention should be flexible, consisting of zooming in and out of various aspects of the classroom to promote student sense-making and classroom equity. The results showed an increase in all three teachers' targets of attention both in terms of frequency and diversity, indicating the deployment of flexible attention to capture various dimensions of a multifaceted classroom. For instance, 7 targets of attention were identified in Fatima's pre-PD discussion, primarily revolving around student characteristics and pedagogy. After the PD, 19 targets of attention were identified in Fatima's discussion, where she focused primarily on student characteristics, pedagogy, classroom climate, and classroom equity. For Amna, a total of 19 targets of attention were identified in her pre-PD discussion, mainly on pedagogy and classroom management. After the PD, Amna's increased the frequency of her noticing to a total number of 29, among which pedagogy, student science ideas, classroom climate, and student characteristics have the highest frequency. Overall, the results indicated teachers' flexible attention to various aspects of the classroom.

Furthermore, teachers' increasingly flexible attention to the multifaceted classroom allowed them to contingently respond to students to promote sense-making and equity. For example, Fatima's response pattern in maintaining and widening the discussion was coherent with her attention to classroom equity. This finding aligns with previous research, such as van Es et al. (2017), who illustrated the relationship between teachers' attention to equity and their equitable teaching practice. The coherence between teachers' attention and response is also found in Robertson et al. (2016) and Richards et al. (2020). However, what the results did not show is that given the competing foci of the classroom, what makes a teacher decide to attend to one aspect and overlook the other? As shown in Chapter 4, human attention is limited and selective in nature. Attention to one aspect of the classroom implies inattention to others. Robertson et al. (2016) coined the notion of 'meta-responsiveness', arguing that expert responsiveness is defined in part by teachers' decision of which facets of attention to foreground in the moment." The notion of meta-responsiveness shares some conceptual similarities with Sherin and van Es's (2009) 'selective attention', which involves deciding where to attend to when observing a classroom. The difference is that Sherin and van Es foreground student thinking over other aspects of the classroom (e.g., classroom management) whereas meta-responsiveness is negotiated in the complexity of the classroom interaction, and there is no simple answer to what teachers should attend to in a given moment. This view resonates with Lefstein et al. (2013, p.13)'s problematisation of dialogic teaching as "a set of dilemmas to consider, concepts to think with, commitments to pursue and balance."

Studies have used mobile eye tracking (MET) to understand differences in novice and expert teachers' professional vision in real-time classroom (Huang et al., 2021) and retrospective video viewing (Keller et al., 2022). Huang et al. (2021)showed that expert teachers had shorter fixation duration and a larger quantity of fixations. Expert teachers also had a smaller proportion of fixations on objects irrelevant to teaching and a wider range of fixation. Future studies can leverage MET to zoom into the moments of pedagogical dilemmas when there are competing foci in the classroom.

In summary, this study showed that teachers could increase their range of attention over class discussion including classroom climate, pedagogy, student science ideas, student lived experience, and classroom equity, enabling them to contingently respond to student talk to promote sense-making and equitable participation. However, it is unclear how teachers manage the competing foci of attention and resolve the dilemmas of what to attend to in a particular moment and what to disregard. Future research is needed to uncover the mechanism of teachers' selective attention.

8.2.4 Engage in knowledge-based reasoning

Knowledge-based reasoning is the process in which teachers draw on various sources of knowledge to make sense of their observations in the class, such as knowledge about the students (KS), content knowledge (CK), pedagogical knowledge (PK), and pedagogical content knowledge (PCK). There is evidence of teachers being increasingly engaged in knowledge-based reasoning after the PD. Before the PD, teachers primarily relied on KS and PK in making sense of their noticing in the classroom. After the PD, teachers increasingly used more PK for knowledge-based reasoning. In this study, CK and PCK were least frequently used for knowledge-based reasoning. This study also illustrated how knowledge-based reasoning supported teachers to contingently respond to student ideas which aligns with the results of existing research that knowledge and situational-dependent skills are moderately correlated in general (See König et al., 2014; König & Kramer, 2016; Meschede et al., 2017).

The low frequencies of CK and PCK could partly be explained by the fact that none of the teachers came from a science or science education background. The individual reading/simulation guide was designed to provide teachers with CK, PK, PCK for the purpose of the simulation. However, there was a lack of evidence of how teachers made use of the materials in the simulation guide for knowledge-based reasoning. Meschede et al. (2017) found a moderate correlation between PCK and teachers' capacity to perceive and make sense of classroom situations. In a recent review of studies undertaken between 2010 and 2020, Kind et al. (2022) found that a teacher's professional knowledge, in particular, CK, and PCK, impacts teaching practices and student learning outcomes in science across the 5-18 age range. Kind and Chan (2019) maintain that flexible PCK allows teachers to adapt quickly in classroom settings in response to students' varied responses and planned instruction, which is an essential part of CR. Therefore, supporting teachers to develop their CK and PCK is critical to promoting the disciplinary practice of science and enhancing the scientific rigour of the discussion.

To support teachers in developing CK and PCK that fosters CR, it is essential to close the gap between knowledge and practice, situating the learning in the context of the teachers' own practice rather than teaching them as inert declarative knowledge. Class videos have been used widely and successfully to support teacher noticing and knowledge-based reasoning (Gamoran Sherin & van Es, 2009; Kleinknecht & Gröschner, 2016; Luna & Sherin, 2017; Tekkumru Kisa & Stein, 2015). This PD programme could incorporate classroom videos to highlight the rich substance of student science ideas and pedagogical dilemmas in their own classroom/simulated class, which would encourage teachers to also use CK and PCK for knowledge-based reasoning in addition to KS and PK. In this PD, the feedback teachers received about their practice mainly came from their peers. This PD programme could benefit from Kleinknecht and Gröschner 's (2016) structured video feedback cycle (VFC), involving multiple cycles of reflection from teachers themselves, their peers, as well as teacher educators. The VFC model brings in multiple voices and alternatives, enriching the dialogic space of teachers' knowledge-based reasoning and expanding their repertoire of CK and PCK.

8.2.5 Experience metaphoric resonance

Metaphoric resonance is a mediating process that emerged during the DBR (after Iteration 2) to support teachers to recognise alternative responses whilst leading a discussion. Mason and Spence (1999) distinguished 'knowing-to act' from 'knowing-about'— it is not sufficient to only know about something, what matters is to know how to act in the moment rather than in retrospect. According to Mason (2002), metaphoric resonance support teachers' knowing-to-act, to bring relevant knowledge, experience, and strategies to the fore. In this study, there is evidence of teachers experiencing metaphoric resonance in the PD to support Mason's claim. For instance, Minahil described how she experienced metaphoric resonance in her post-PD discussion, recognising the structural resemblance between a case study in the workshop and her current situation, which allowed her to diverge from her usual response pattern.

Metaphoric resonance could potentially address one of the persistent challenges in PD for dialogic teaching, i.e., supporting teachers to diverge from their routine, established practice, discourse pattern, and habits, which are often unconscious in the moment of action (Lefstein, 2008). Many studies found that the discourse pattern between teachers and students tends to remain unchanged after PD and reforms (e.g., Lefstein, 2008; Pehmer et al., 2015; Ruthven et al., 2017; Sedova et al., 2014; Wells & Arauz, 2006). For example, during a reform that promotes dialogic teaching in the

UK, Lefstein (2008) found that despite teachers' conscious attempt to initiate a discussion with an open-ended question, they tended to funnel student ideas to the 'correct' answer during the discussion. In other words, knowing dialogic principles is not enough, especially during classroom talk with many stimuli and time pressure (Sedova et al., 2014). Lefstein (2008) argued that the micro-level of interactions in the classroom operates subconsciously and is run by teachers' established routines and habits. PD needs to support teachers to overcome certain habits that no longer serve their students and practice. According to Kahneman's dual-system theory (2013), people have two cognitive processes for decision-making. The first process is System 1, which Kahneman refers as fast thinking, that enacts out of habit, and it is automatic, subconscious and intuitive. On the other hand, System 2, the slow thinking, is reason-based, deliberative and effortful. It is important to note that there is no superiority between the two systems. Teachers need System 1 to manage a large number of stimuli and fast pace in the classroom to make decisions in real time (Roth, 2002) and System 2 to reason about student ideas and wrestle with pedagogical dilemmas (Lampert, 1985). The orchestration of Systems 1 and 2 in teaching is well described by Sawyer (2004) as disciplined improvisation.

The question is, how do teachers swiftly shift between System 1 and System 2? Mason and Metz (2017) augmented Kahneman (2013)'s dual-system theory and inserted a System 1.5 between Systems 1 and 2 that is based on affect, such as experiencing metaphoric resonance. As Mason and Spence (1999, p. 135) said: "No-one can act if they are unaware of a possibility to act." Metaphoric resonance plays a crucial role in "awakening" teachers in the midst of the discussion and in recognising alternative possibilities. In this study, Minahil's account showed that she experienced metaphoric resonance in the moment that she recognised that the situation she was facing bears a structural resemblance to a case study that she encountered during the workshop, leading her to widen the dialogic space rather than shutting it down. Amna also described her experience of metaphoric resonance, moments when she recognised a popcorn discussion (a case study in Workshop 2) and sense-making discussion (a case study in Workshop 3).

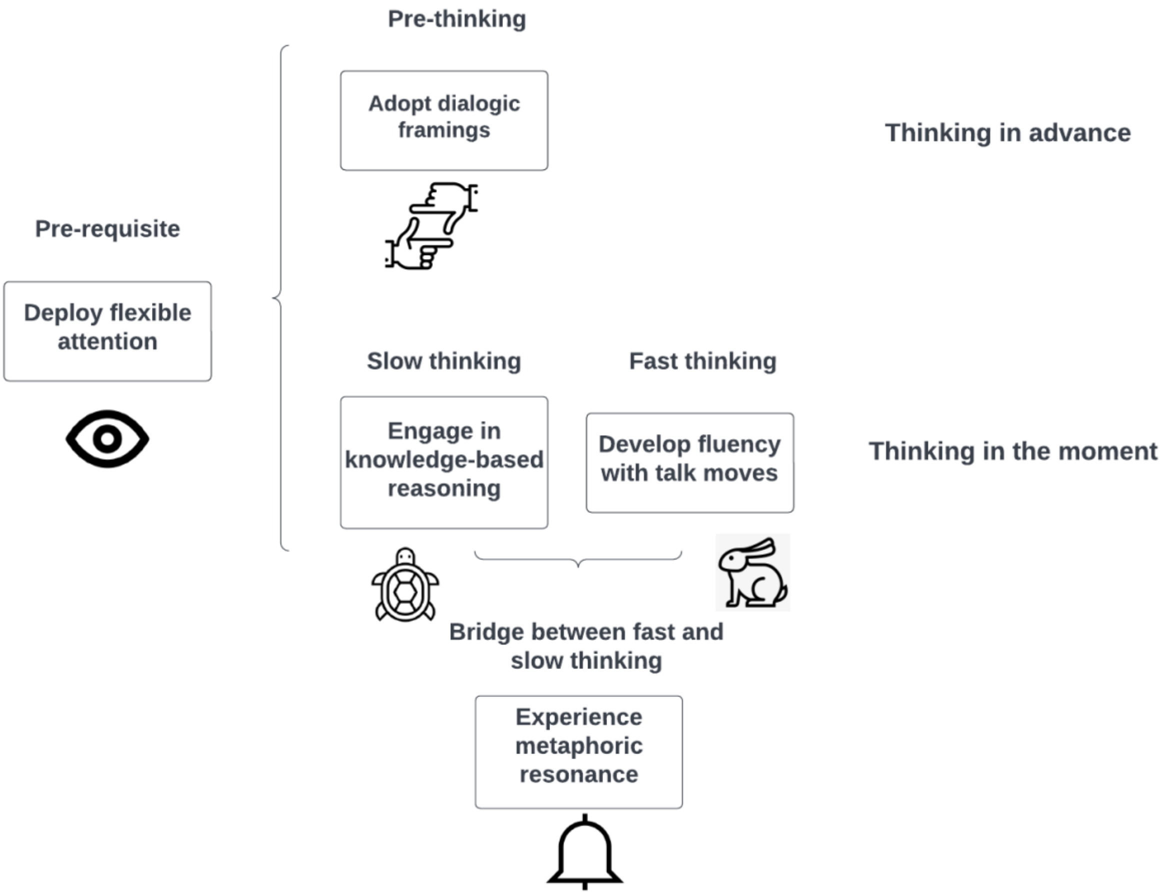
Originating from the literature of teacher noticing (Mason 2002), the notion of metaphoric resonance is rarely studied in dialogic teaching. Future studies are needed to further test the affordances of metaphoric resonance and better understand the mechanism of metaphoric resonance in the context of dialogic teaching. Despite the promise of metaphoric resonance to bridge System 1 and System 2, metaphors have limitations. Metaphor involves a partial transformation of one kind of thing under the guidance of another kind (Dent-Read & Szokolszky, 1993). Therefore, in a metaphor, there is no perfect mapping of one thing to another. Mason maintains that metaphors have both strengths and weaknesses—"in stressing some features, they ignore or distort others. While capturing one way of perceiving, they may block or rule out others (2002, p. 23)." There is also potential confusion or clash in metaphor associated with particular words, which also varies in cultures and contexts (E. C. Collins & Green, 1990). Therefore, we cannot assume that metaphors that work in one context and setting will transfer to another. One potential solution is for teachers to come up with their own metaphors and labelling of the incidences and strategies that they deem important to establish a shared understanding of the metaphors.

8.2.6 Relations among the five mediating process

These five mediating processes were observed to foster teachers' CR in this study, together forming a preliminary learning theory of CR. I have discussed the implication of each mediating process as well as their limitations and potential directions for future research. To summarise, teachers' development of CR could be fostered by supporting teachers to 1) adopt dialogic framings, 2) develop fluency with talk moves, 3) deploy flexible attention, 4) engage in knowledge-based reasoning, and 5) experience metaphoric resonance. These five mediating processes showed that CR is not just 'thinking-in-the- moment' (i.e., reflection-in-action), but a combination of 'thinking-in-advance'(e.g., adopting a dialogic framing), 'fast-thinking', and 'slow-thinking' (e.g., knowledge-based reasoning), thus challenging the assumption at the beginning of the study that CR is only situated in the moment. Mason (2011) also spoke about the affordances of prospective preparation for future noticing, i.e., imagining oneself noticing an opportunity and acting differently. According to him, such prospective imagining allows the moment of noticing to move closer and closer to the moment of action, eventually replacing the habitual reaction with a fresh response. In other words, CR is distributed across the past, present, and future, and it is possible to prepare for CR, such as adopting a dialogic framing of the discussion in advance.

This study did not show the relationships among the five mediating processes that led to CR. One possible hypothesis (illustrated in Figure 8.1) is that flexible attention is the prerequisite of CR based on the assumption that we cannot respond to something that does not enter the attentional gate. In addition to Kahneman's fast and slow thinking that acts in the moment, there is also 'thinking-advance' that unloads some of the cognitive load in the moment. Having fluency with talk moves can support teachers' fast-thinking whereas knowledge-based reasoning is a type of slow-thinking. Finally, metaphoric resonance serves as a bridge to 'awake' teachers in the moment to recognise alternative possibilities, to shift from fast-thinking to slow-thinking. Future studies should therefore further develop and test this preliminary theory in other settings and cultural contexts and uncover the relationships among the mediating processes.

Figure 8.1 A hypothesis of relationships among the five mediating processes



8.3 Exogenous and endogenous design features

Four high-level conjectures served as guidance for the overall design and structure of PD, the workshops, and the scripting of simulation scenarios.

1) Inquire with teachers rather than prescribing solutions
2) Combine fast and slow thinking
3) Situate learning at the edge of teachers' competency
4) Leverage interleaved practice (instead of massed practice)

The design features in this study embodied the four high-level conjectures summarised in Table 8.1.

Table 8.1 Embodied design features after 4 iterations

High-level conjectures	Embodied design features
High-level conjecture 1: Inquire with teachers	Guided collaborative inquiry, a repertoire of talk moves organised by dialogic functions; case studies
High-level conjecture 2: Combine fast and slow thinking	Mixed-reality simulation (MRS), collective reflection (both post-simulation and during the workshop)
High-level conjecture 3: Situate learning at the edge of teachers' competency	Increasing complexity of MRS scenarios over time
High-level conjecture 4: Leverage interleaved practice	Varied MRS scenarios and types of discussions

Chapter 7 discussed in detail how the design features in Table 8.1 produced the mediating processes. The following design conjectures were found in the DBR and supported by empirical evidence.

1) Being exposed to dialogic framings in the MRS, engaging in guided collaborative inquiry and case studies can lead teachers to adopt dialogic framings.
2) Practising talk moves from the workshop and simulation guide in the MRS can lead teachers to develop fluency with talk moves.
3) Reflecting on and being explicit about what teachers notice in the MRS during collective reflection can help to teachers to develop flexible attention across various dimensions of during class discussion.
4) Collectively reflecting on decision-making in the MRS as a group provides teachers with opportunities to engage in knowledge-based reasoning.
5) Case pupils in the MRS, case studies that bear structural resemblance to teachers' own classrooms, and talk moves labelled by dialogic functions can lead teachers to experience metaphoric resonance.

Because the mechanisms of the PD are understood, it is possible to substitute for design features if one is not available. For instance, MRS is not yet cost-effective and widely available for PD and initial teacher education. Because we understand the role of MRS played in the design, such as enabling teachers to adopt dialogic framings, it is possible to substitute with design features that can potentially generate the same effect, such as providing teachers with the framing of discussion and experimenting with it in their classrooms. Therefore, understanding the mechanisms allows the design to be more easily adapted and tested in other contexts even when some design features are not available, thus enhancing the adaptability, sustainability, and potential for scalability of the design.

It is important to highlight that these design features are exogenous, developed for the purposes of the PD and research, predominantly reflecting the researcher's or "outsider's" voice (Tabak, 2004). There were endogenous features already present in the learning environment, such as the community of practice shared among Fatima, Minahil and Amna (see Section 7.6.1). Tabak (2004) cautioned about the danger of overattributing success to exogenous design and overlooking the role of the endogenous elements. In this study, the community of practice shared among the three teachers allowed them to take their learning from the PD and interweave it into their daily practice, exchanging feedback, and supporting each other during challenging times. The role of such a strong community of practice should be taken into account as part of the mechanisms of the PD. Would teachers who do not have such a community of practice experience the same kind of improvement as Fatima, Minahil, and Amna? As mentioned earlier about the challenge during the pandemic which caused the high attrition at the school, only four teachers completed the four iterations of the PD. The partner teacher of Zainab (the fourth teacher who completed the PD) left after workshop 4, and Zainab did not provide the post-PD video. It is possible to speculate that Zainab did not have such strong support from a community of practice as the other teachers, which might be the reason that she did not end up providing the post-PD video.

One of the limitations of Sandoval's (2014) conjecture mapping is that it focuses on helping design researchers to explicate the exogenous design features within a given context. As a result, it creates an impression that learning was only attributed to the exogenous design features. Tabak (2004) showed that learning goals could be met through a different activity structure that was not part of the exogenous design. In this study, it was clear that the community of practice played an important role in teacher learning; however, it was unclear how it supported teachers to develop CR, i.e., how it connected to other design features and mediating processes. Sandoval (2014, p. 31) suggested seeking contextual various to alleviate this problem, "reframing the task of design research as recreating and interpreting outcomes across multiple settings and tracing how both exogenous and endogenous factors contribute to those outcomes." Therefore, future studies could test this PD design in various contexts and examine the differences in terms of endogenous features across the learning environments to shed light on how they contribute/hinder the development of CR.

The entanglement between exogenous and endogenous features reflected the dialogic nature of DBR for PD, i.e., researchers work with practitioners within their environment to co-create rather than imposing a pre-packaged PD on practitioners. Tabak (2004, p. 231) viewed DBR as "a process of iterative co-construction between 'outsiders' and 'insiders', which can better develop a rich understanding of the complex ways that could support novel forms of learning.

8.4 Re-organising talk moves to advance student thinking

Reorganising talk moves as dialogic functions in a dialogic space emerged after Iteration 3 of the DBR. This study proposed to conceptualise discussion using the metaphor of dialogic space and re-organise talk moves according to their dialogic functions, i.e., to widen, deepen, maintain, and shape the dialogic space to support students to advance their thinking. The purpose was to address the limitations in Michaels and O'Connor's (2015)'s conceptualisation of talk moves as tools from Vygotsky's work on tools as mediational means (Vygotsky, 1978). To Michaels and O'Connor (2015), talk moves are tools that can be used for various purposes, which they refer to as four foundational goals, such as helping individual students share, expand, and clarify their own thinking and help students listen carefully to each other. There are a number of challenges surrounding the current conceptualisation of talk moves. O'Connor and Michaels (2019) found that sometimes talk moves are used in a robotic and perfunctory manner. Furthermore, teachers' use of talk moves did not necessarily help students to move their thinking forward (Coffey et al., 2011; Doubler & Paget, 2016; Harris et al., 2012; Hennessy & Davies, 2020; Ruthven et al., 2017). Wegerif (2011) challenged the idea that dialogue can be adequately studied through a focus on mediation by tools. To Wegerif, dialogue is not a tool but rather a relation of voices. Conceptualising talk moves as tools positions student ideas as "things" to mediate to reach certain goals rather than "voices", that resonate, merge, clash, and create new ideas.

Shifting from the metaphor of tools into a metaphor of a dialogic space has significant implications. In their seminal work, *Metaphors We Live By*, Lakoff and Johnson (1980) maintained that metaphors shape our perception and thought, and influence the actions we take. Shifting from the metaphor of tools into a metaphor of a dialogic space implies an ontological shift from seeing student ideas as individual "things" to seeing them in relation with each other. In a dialogic space, the teacher's role is not to use tools for a particular goal or to address a particular challenge, but rather to widen, deepen, maintain, and shape the dialogic space (see Appendix 11 for the whole list of talk moves organised according to dialogic functions). The metaphor of dialogic space allows teachers to de-identify from the individual ideas and instead identify with the whole dialogue. Student thinking is advanced as they collectively improve the dialogue together. In a science discussion, improving dialogue means better making sense of things that learners are grappling with and looking for more powerful explanatory models.

In this study, there is evidence that teachers could relate to the metaphor of a dialogic space[12] and adopted the language of opening, widening, deepening, and maintaining a space when reasoning about their practice. Teachers also highlighted that this conceptualisation gave them the language to communicate with their colleagues, consciously incorporating talk moves into their teaching, and identifying areas for improvement in their practice. However, it is unclear whether such conceptualisation of talk moves can support teachers in advancing student thinking. The reason is that this study focused on teachers' response patterns and did not include student learning outcomes. Therefore, further studies are needed to test the affordances of this new conceptualisation of talk moves in advancing student thinking.

8.5 MRS as an emerging technology for dialogic teaching

8.5.1 Affordances

Mixed-reality simulations (MRS) have unique affordances to support teachers in developing dialogic practice in the development of CR.

1) **Contextualised and varied scenarios**: MRS could support CR as an adaptive expertise by exposing teachers to a variety of contextualised scenarios. In this study, teachers experienced four scenarios of the classroom and three types of discussions.

[12] Dialogic space was introduced as sense-making space in the PD to emphasise the scientific practice of sense-making.

2) **Close to real-life practice:** MRS afforded teachers an embodied experience similar to teaching in a real classroom, instead of just clicks of a mouse or selecting from a drop-down menu.

3) **De-composition and re-composition of practice**: MRS allowed the de-composition and re-composition of teaching practice, having teachers focus on a number of targeted goals, to "learn to kayak in the calm waters" (Grossman, Compton, et al., 2009, p. 2076). In this study, classroom management was purposefully kept at a minimal level to have teachers focus on student science ideas, lived experience, and classroom equity issues. The complexity of the simulation and demand for teachers' skills increased over time, progressing from eliciting student ideas, to balancing between science content and student ideas, and eventually orchestrating multiple student ideas during scientific argumentation.

4) **Combine fast and slow thinking:** MRS afforded the teachers to engage in both fast thinking in the moment with the avatar students and slow thinking to reflect with the colleagues and host avatars about their practice.

5) **Low-stakes environment**: MRS is a low-stakes environment, where teachers can safely practise and experiment without worrying about negatively influencing students.

At the beginning of the study, there was a question about whether practising with avatar students in a simulation is antithesis to dialogic teaching, the essence of which is authentic relationships. In this study, teachers reported feeling a sense of connection with the avatar students. In addition to self-report, the sense of connection that teachers felt was also manifested in their interactions with the avatar students, e.g., asking how they were doing, showing curiosity about their lives, and showing concern for students who did not participate in the discussion. This study showed that teachers did not only treat the simulated classroom as a vehicle for practising teaching, but they also developed a personal connection with the avatar students.

Despite these unique affordances, it is important to note that MRS did not work in isolation to foster CR. In fact, MRS was nested within an ecosystem of design features to support teacher learning and worked in combination with other design features (e.g., guided collaborative inquiry, collective reflection, and talk moves), giving rise to mediating processes, which led to CR (see the final conjecture map in Figure 7.33). For example, the combination of MRS, case studies, and guided collaborative inquiry supported teachers in recognising various discussion framings, leading to the drastic shift of teachers' response patterns in Simulation 2 (for details see Section 7.3). MRS and case studies together allowed teachers to experience metaphoric resonance to shift their response pattern in the moment (see Section 7.7).

Furthermore, this PD programme used an instructional design framework (i.e., Teaching for Understanding (TfU). MRS was interwoven into the fabric of the instructional design, and positioned as an opportunity for teachers to enact their learning from their guided collaborative inquiry in the workshop. The structure and progression of the simulations were grounded in evidence-based learning principles (e.g., interleaved practice, situating learning at the edge of learner's competency).

8.5.2 Beyond an 'exercise machine' and leveraging the full potential of MRS

So far, the application of MRS for teacher education and teacher professional development is mainly in two areas: practising a certain teaching technique or improving teachers' self-efficacy. For example, Hudson (2021) used MRS to have teachers practise the 'constant time delay procedure', an evidence-based practice for learners with special needs. In Geraets et al. (2021), teachers practised two techniques, namely cold calling and error reframing in MRS. In Walters et al. (2021), teachers practised implementation of the prompting sequence. Lee et al. (2021) used MRS to support teachers to practise eliciting strategies. MRS was also often used to support novice teachers to improve self-efficacy (e.g., Grant & Ferguson, 2021; Gundel et al., 2019; Gundel & Piro, 2021). This study showed that the potential of MRS is much more than being an 'exercising machine' to practise techniques and improve self-efficacy. Bondie et al. (2021) suggested that MRS can serve as a vehicle for developing teachers' complex decision-making skills. This study showed that MRS could approximate the complexity of the classroom and support teachers not only in the technical aspects of teaching but also in the intellectual, improvisational, contexual, and even relational aspects.

In this study, MRS was leveraged to address all aspects of dialogic teaching:

1) Technical: practising and developing fluency with talk moves.
2) Intellectual: engage in sense-making with avatar students about a puzzling phenomenon and knowledge-based reasoning in the post-simulation reflection with colleagues and the host avatar.

3) Improvisational: engage in fast thinking and exercise professional judgment in the situation to decide when to widen, deepen, maintain and shape the dialogic space
4) Contexual: being exposed to various types of science discussions in an instructional sequence
5) Relational: developing a sense of connection with avatar students.

8.5.3 Careful design of MRS

MRS is a sandbox; it itself needs to be thoughtfully designed with the target learning outcomes in mind. The careful scripting of the scenario and skilful acting of the simulation specialist plays a vital role in determining the effectiveness of the learning experience. In this study, each simulation scenario was carefully designed and theoretically grounded in the literature. For instance, when scripting student ideas, I drew on the literature on ambitious science teaching (e.g., Windschitl et al., 2018), student misconception/alternative conceptions (e.g., Driver et al., 2014), complex causality (e.g., Grotzer et al., 2013; Grotzer & Basca, 2003) in addition to my personal experience as a teacher. Furthermore, I developed a deep understanding of the teaching context in the school, which enabled me to script the scenarios in a way that was contextually relevant and familiar to the teachers, facilitating the transfer of their learning to their real classrooms. Last but not least, the relevance and cultural sensitivity of each scenario was ensured by gathering feedback from teachers and teacher coordinators.

8.5.4 Guiding principles in using MRS for PD

Bondie et al. (2021) identified five guiding principles in applying MRS for teacher learning in terms of 1) learning design, 2) avatar and interactor learning, 3) interactor training, 4) time and distance, 5) complex practices in a sociocultural contexts. In this study, I identified 10 principles that guided the use of MRS in this study, which could serve as potential guidance for future studies:

1) Position MRS as one component of the whole ecosystem of PD, choose an evidence-based instructional design framework (e.g., Teaching for Understanding) and interweave MRS into the fabric of the instructional design.
2) Ensure MRS scenarios are close to teachers' context of practice (e.g. age group, subject).
3) Draw on the literature to script students' ideas (e.g., typical student alternative conceptions).
4) Foreground the most relevant aspects of the learning goal in the simulation (e.g., minimising classroom management if it is not the focus of the learning for the session).

5) Consider the context, needs of participants, and learning goals to determine the participant structure of the simulation (e.g., individual sessions, co-teaching sessions).
6) Combine fast thinking in the simulation with slow thinking after the simulation (e.g., provide teachers time for reflection and feedback after the simulation.)
7) Situate teachers' learning at the edge of their competency and make sure the scenarios are just challenging enough for teachers to make progress.
8) Leverage interleaved practice to support teachers in developing sensitivity in various situations.
9) Ensure skilful acting of the simulation specialist, preferably with knowledge about teaching and the culture.
10) Work closely with the practitioners at every step to ensure the relevance, cultural sensitivity and appropriateness of the MRS scenarios.

8.6 Studying 'high tech' in the context of Pakistan

As discussed in Chapter 3, the Pakistan education system suffers from low-quality, inaccessible teacher education programs and a lack of opportunities for PD. MRS is at its early stage of application in teacher learning. It is not yet cost-effective and has primarily been studied in the context of the global North (e.g., Bautista & Boone, 2015; Dalinger et al., 2020; Dieker et al., 2016; Gundel et al., 2019; Hudson et al., 2019; Lee et al., 2021). This study sought to address the inequitable predominant focus of research on MRS to date in the global North by working directly with teachers in Pakistan, to understand the application of MRS in the context of an LMIC and include practitioners in the design and implementation of a technology-enhanced PD. Although Edopia school was not representative of schools in Pakistan, it provided an ideal testing ground for this new technology in the cultural context of Pakistan.

This study showed a mix of excitement and apprehension about MRS when it was first introduced to the teachers. Support and assurance from the facilitator play an important role in helping teachers to feel comfortable with this new technology. In general, teachers welcomed MRS as a novel technology for supporting their professional development. Furthermore, this study showed the importance of involving practitioners in the design and implementation of the technology, especially due to the nature of MRS that requires thoughtful scripting that is close to the classroom context and is culturally sensitive and appropriate. This study echoed the assertion by Hennessy et al. (2022) that working with practitioners in LMIC contexts is important to ensure that adaptability is engineered in the technology rather than implanting the technology as a solution.

8.7 Reflection on using DBR as a research method

DBR is rarely used in PD for dialogic teaching (studies by Chang, 2022; Hennessy et al., 2021; Wilkinson et al., 2017 are exceptions). While there are a number of challenges associated with DBR, such as conducting multiple iteration cycles within the time span of a PhD (Herrington et al., 2007), my experience illustrates that DBR is not only a feasible method for doctoral studies, but it is also academically enriching and personally rewarding. On an academic level, this study was theoretically enriched by working closely with teachers, observing their practice, and listening to their feedback. Working with practitioners opened a dialogic space for the emergence of new ideas. For instance, organising talk moves using dialogic functions and metaphoric resonance emerged during the DBR. CR as a newly defined construct also evolved along with the iterations.

Furthermore, close collaboration between practitioners and researchers maximised the chance to create a real impact in the classroom. This programme was very positively received by the teachers despite the challenges of the pandemic. Teachers reported that they learned new pedagogies and strategies that they were not aware of before and they could incorporate their learning from the PD into their real classroom, such as leading various types of science discussions. At the end of the study, teachers asked for more PD opportunities like this and suggested that all teachers at the school (not just the science teachers) could benefit from this programme.

On a personal level, it is motivating to work with practitioners and to see my work in action among the teachers not just on paper. Working with practitioners helped me identify problems in the design, and motivated me to do further research, learn new skills (e.g., designing the asynchronous module with Typeform), and create new knowledge. I was constantly inspired by teachers' thoughtful questions and insightful comments, which opened more opportunities for thinking and learning together. At the end of this study, the teachers and I talked about designing a continuation of this PD programme. The school leader was also willing to continue the collaboration. The experience of DBR is dialogic in nature: one iteration poses new questions to the next, and one study opens up new possibilities for more.

8.8 Limitations and future research

8.8.1 Limitations of the study

Small sample size

The pandemic caused an exceptionally high attrition rate at the school, which reduced the number of teachers who completed the PD to four, of which three provided both their pre-and post-PD discussion videos. The result about the effectiveness of the PD in this study is limited by its small sample size in a specific context and thus not immediately generalisable to other contexts. However, the mechanisms underlying the PD and promising learning pathways were identified, which could be studied, tested, and refined in other educational and cultural contexts.

Sustainability of learning in the PD programme

I was not able to travel to Pakistan to work with the teachers and teacher coordinators in person and observe multiple lessons due to the traveling restrictions during the pandemic. As a result, findings in this study were based on one pre-PD and one post-PD discussion from each teacher. Therefore, it was unclear whether the response patterns in the post-PD discussion were sustained in the long run. Nonetheless, teachers' consistent tendency towards dialogic practice in the simulations provided some evidence for the sustainability of change. A follow-up study with the three teachers will be conducted next year to assess the sustainability of their learning from this PD programme.

Changes in student dialogue

Furthermore, this study focused on teachers' third turn and their role in shaping the classroom discourse. Nonetheless, students equally have a substantive and generative role in shaping the classroom discourse (Maskiewicz & Winters, 2012). Teachers' dialogic moves could model for students how to respond to each other's ideas. For example, teachers could model for students how to respond to a peer's idea by widening the dialogic space, asking for more information and building on the idea (O'Connor & Michaels, 2019). Therefore, future studies could investigate how students respond to teachers' dialogic moves and whether it changes student discourse patterns.

Impact on student learning

The findings of this study focused on changes in teachers' response patterns, but they did not necessarily indicate the quality of the discussion in terms of scientific rigour, the classroom talk culture or the advancement of student thinking. Future studies should also investigate the impact of teachers' response patterns on students' learning outcomes (e.g., Howe et al., 2019). Therefore, in the follow-up study, I will focus on how teachers' changes in their discourse patterns influence student learning and student talk.

Affordances of the reframed talk moves

This study proposed a re-organisation of talk moves based on dialogic functions for the purpose of advancing student thinking in a discussion. Though there is evidence of teachers adopting the language of these metaphors and dialogic functions, it is unclear whether such adoption could lead to the advancement of student thinking. Future research is needed to study the shift in student thinking before and after the discussion to test the affordances of this new organisation of talk moves.

Appearance of avatars and cultural background of simulation specialist

The design of the simulation was limited in terms of the appearance of the avatar students. As discussed in Chapter 4, designing new avatars that are representative of the demographics of the school in terms of appearance requires significant financial and time investment, which was not feasible in this study. Several measures were used to mitigate this limitation, such as soliciting feedback from teachers and teacher coordinators in each iteration and carefully scripting the scenarios based on the observation of the classroom context in the videos provided by teachers. Based on teachers' feedback, it seems that they could look beyond the appearance of the avatars and connect with their personalities, which does not seem to influence their learning in the PD. In contrast, previous studies showed that people tend to work with avatars possessing similar physical features to themselves (e.g., van der Land et al., 2015; Wallace & Maryott, 2009). It would be interesting to investigate in the future the extent to which the appearances of avatars influence teachers' perceptions and sense of connection.

Furthermore, the simulation specialist in this study is from the US and does not have a cultural background in Pakistan. Her portrayal of the avatars also had a US accent. Again, these limitations did not seem to stop the teachers from connecting with the avatar students and even seeing their own students through these avatars. However, this might have to do with the unique context of Edopia School, where many of the students are expatriates. Therefore, the simulation technology could benefit from more flexible adaptation of avatar appearances and having a diversity of simulation specialists from various cultural backgrounds.

Classroom equity beyond equitable participation

Also, in the study, classroom equity was only addressed as equitable participation that originates from various personalities and student dynamics. There are many other forms of equity issues present in our society and classroom, such as learning needs, socioeconomic status, race, and gender. Some equity issues are more prominent in one context than others. This study chose to limit classroom equity as equitable participation because it was what the teacher coordinators identified as most relevant for their school context. In future studies, the definition of equity should be re-examined, and potentially expanded to include other forms of equity issues present in a given context.

8.8.2 Methodological limitations

Limitations of the conjecture maps

This study attempted to address some of the criticisms of DBR (A. Kelly, 2004), such as lack of rigour and argumentative grammar by using Sandoval's (2014) systematic conjecture mapping to trace the path from design features, to mediating processes, and to outcomes. However, one of the limitations of conjecture mapping is its focus on exogenous design features without necessarily understanding how the endogenous elements are already at work within a learning environment. Future studies could test this PD design in multiple settings to understand how both exogenous and endogenous elements contribute to learning outcomes. Another methodological limitation of the conjecture map is that it does not shed light on the relationships between the mediating processes. One possible hypothesis was proposed in Section 8.2.6. Future studies are needed to test this hypothesis and shed light on how the mediating processes work together.

Challenges in capturing teachers' thinking in the moment

Another methodological limitations is the use of retrospective interviews to uncover teachers' attention in the moment and knowledge-based reasoning. It is important to acknowledge that a retrospective account of teachers' in-the-moment thinking a proxy for reflection-in-action because it is possible to construct a narrative afterwards to justify the actions (Mason 2002). However, Sherin et al. (2011) found that such concern for ad hoc reconstruction of noticing did not materialise in their studies—teachers could recall their thinking simply from being shown the still image or a few seconds of the video. This study attempted to reduce the chance of ad hoc reconstruction by having teachers choose to pause the video at any moment that they found interesting and noteworthy rather than being asked directly about their in-the-moment thinking.

Capturing teachers' reflection-in-action has been very challenging methodologically since it is impossible for teachers to lead a discussion and, at the same time, speak about their thinking process, which will inevitably disrupt the flow of the discussion. To date, there is not yet a method that could fully address this challenge. One of the methods involves the use of wearable technology, a small video camera that could be attached to the bill of a hat, a hand-held remote, and a recording module. This technology allows teachers to capture videos in action (Dyer & Sherin, 2016; Luna, 2018; Luna & Sherin, 2017a; Russ & Luna, 2013). The recordings are then used to prompt teachers to recall their in-the-moment thinking, which is also retrospective in nature. One potential area to explore is to further shorten the time and distance between the action and retrospection. For example, researchers could interrupt the teachers and ask about their thinking, which is not feasible in a real classroom but could be done in a simulated classroom. Therefore future studies could test the affordances of simulation to capture teachers' thinking in the moment.

Chapter 9 Conclusion

9.1 Research summary

Teachers' responses to student contributions, the third turn in a typical teacher-student exchange, play a critical role in determining whether students have the opportunity to engage in collective sense-making in a dialogic space (Park et al., 2017). Orchestrating productive discussions in dialogic teaching is challenging—it is not only technical (making use of a variety of techniques such as talk moves), but also intellectual (engaging in knowledge-based reasoning to make pedagogical decisions), improvisational (responding to student talk in the moment), contextual (adapting to the context and situation), and relational (relating to students and being curious about their ideas). This thesis revolves around one big question—how can we support teachers to manage the complex work of dialogic teaching to think and act in the moment, i.e., to contingently respond to student talk in a way that promotes collective sense-making and classroom equity?

Teachers' adaptive expertise to respond to the dynamic flow of student talk in the moment to promote collective sense-making and classroom equity is defined as contingent responsiveness (CR). This study moved beyond a simplistic narrative of 'what works' to uncover the mechanisms that explain 'how' an innovation works. Using a designed-based research (DBR) method, this study produced usable knowledge in form of a design of a PD programme and a series of simulation scenarios and at the same time advanced the learning theory, shedding light on how to support teachers to develop CR in dialogic teaching.

This research took place in a democratic school in Islamabad, Pakistan. Due to the pandemic, the study was conducted remotely. Four teacher coordinators participated in the co-design and refinement of the workshops throughout four iterations. The PD design embodied the improvisational, technical, intellectual, contextual, and relational nature of contingent responsiveness.

The PD programme had two components:

1) Four workshops, where teachers engaged in collaborative and guided inquiry, and collective reflections to develop conceptual understanding of dialogic science teaching and learn about various talk moves (Michaels & O'Connor, 2012).

2) Four simulation sessions, in which teachers put into practice their learning from the workshops by orchestrating a science discussion in a virtual classroom with avatar students, just as a pilot learns to fly a plane in a simulator (Dieker et al., 2013).

To evaluate the effectiveness of the PD (Research question 1), I conducted an epistemic network analysis (ENA) to compare teachers' response patterns to student talk in their real-life classes before and after the PD (Shaffer et al., 2016). Three teachers participated in four design cycles and provided both pre-and post-PD video classroom recordings, on which the analysis was based. Using the metaphor of dialogic space (Wegerif, 2010), teachers' responses were operationalised as widening, deepening, maintaining, and shaping the dialogic space, which I refer to as 'dialogic functions'. ENA showed a significant difference in the response patterns of the three teachers before and after the PD both visually and statistically, indicating the effectiveness of the PD in supporting teachers to develop CR. For instance, teachers shifted from a pattern of response of initiate-feedback to widen-maintain.

To uncover the mechanisms that led to the change in teachers' response patterns (Research question 2), I used conjecture mapping as a systematic way to trace the path from design features, to mediating processes, and then to learning outcomes (Sandoval, 2014). The conjecture map was refined after each iteration, which improved the design and learning theory over time (See Figure 9.1).

The emergence of each mediating process was supported by empirical evidence in this study:

1) Adopting dialogic framings: Teachers shifted from a monologic framing (e.g., interactive lecture) before the PD to dialogic framings of science discussions (e.g., consolidation discussion) after the PD. These findings provided further evidence to support the coherence between framing and response (e.g., Richards et al., 2020; Russ & Luna, 2013), i.e., the teacher's response is coherent with their framings of the situation. Such findings have strong practical implications, highlighting the importance of supporting teachers to recognise their own framings and adopt a variety of dialogic framings in their practice, which will support the shift of their discourse pattern.

2) Developing fluency with talk moves: Teachers demonstrated fluency with talk moves over time, evident in their increased use of productive talk moves – both in frequency and diversity – in the simulations and pre- and post-PD discussions

3) Deploying flexible attention: There was an increase in all three teachers' targets of attention both in terms of frequency and diversity, indicating the deployment of flexible attention to capture various dimensions in a multifaceted classroom.

4) Engaging in knowledge-based reasoning: there is evidence for the increase in the frequency and diversity of knowledge in teachers' knowledge-based reasoning after the PD, especially in KS and PK.

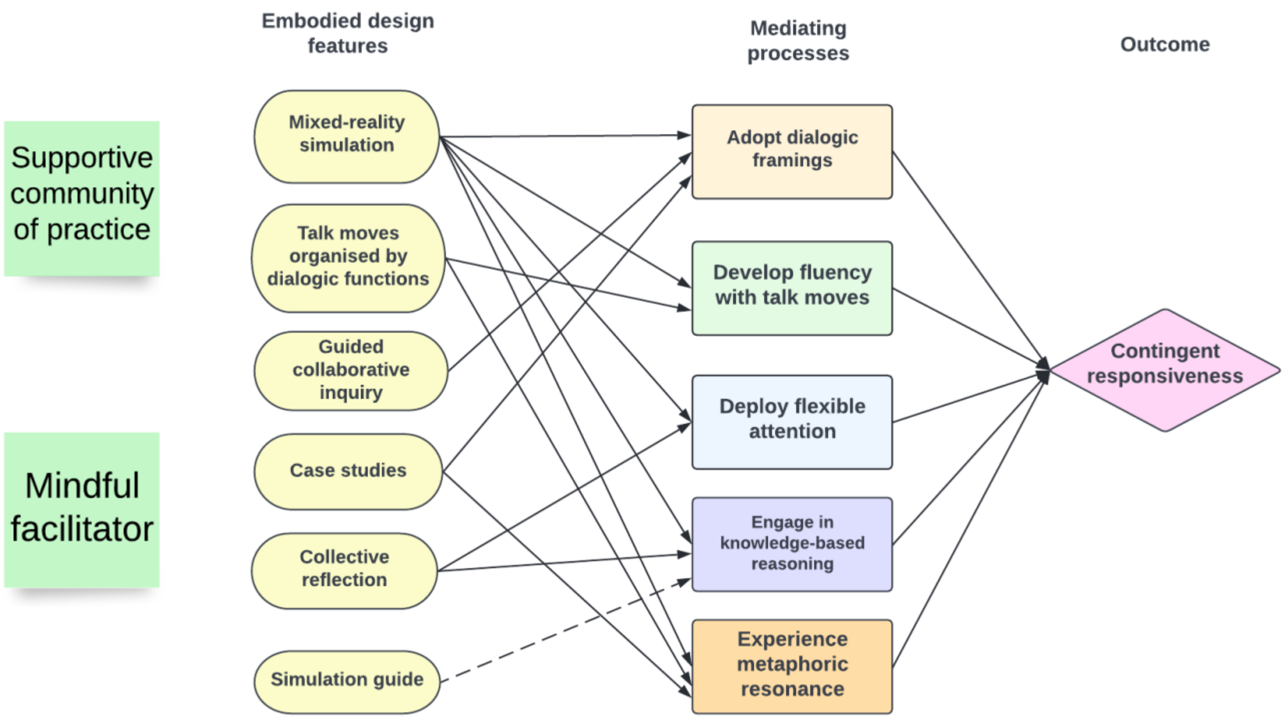
5) Experiencing metaphoric resonance: teachers' experience of metaphoric resonance is evident in their retrospective accounts of their thinking in the moment. Metaphoric resonance supported teachers to recognise alternative possibilities in the moment, leading them to diverge from their usual discourse pattern to take up a more dialogic response.

These five mediating processes challenge the assumption at the beginning of the study that CR is only situated in the moment. A mechanism such as adopting dialogic framings shows that it is possible to prepare for CR in advance. Therefore, CR can be thought of as a combination of prospective thinking (thinking-in-advance), fast-thinking, and slow-thinking.

The causal relations between each mediating process to CR (theoretical conjectures) and the connections to design features (design conjectures) were established based on empirical observation.

Figure 9.1 summarises design features, mediating processes, and outcomes after four design cycles. Solid lines represent relations supported by empirical evidence, and the dotted line represents hypothesised relations that were not observed in this study.

Figure 9.1 Final conjecture map



9.2 Contributions

9.2.1 Theoretical contributions

1) Developing a preliminary learning theory for CR

This study proposed a preliminary learning theory of contingent responsiveness as an adaptive expertise: adopting dialogic framings, developing fluency with talk moves, deploying flexible attention, engaging in knowledge-based reasoning, and experiencing metaphoric resonance can support teachers to contingently respond to student ideas in the moment to promote collective sense-making and classroom equity. Future studies should therefore further develop and test this preliminary theory of CR in other educational settings and cultural contexts. These mechanisms could potentially be transferred and tested in other adaptive expertise, such as problem-solving, negotiation, and conflict resolution.

2) Understanding the mechanisms of the PD

Furthermore, this study shed light on how to generate these mediating processes from design. This study showed that adopting dialogic framing is enabled by a combination of MRS, guided collaborative inquiry, and case studies. Teachers could develop fluency with talk moves using MRS and a list of talk moves provided in the workshop and simulation guide. Teachers' development of flexible attention and engagement with knowledge-based reasoning could be supported by MRS and collective reflection after the simulation. Finally, teachers experienced metaphoric resonance, which was enabled by a combination of MRS, talk moves organised by dialogic functions, and case studies.

Because the mechanisms of the PD are understood, it is possible to substitute design features with other ones that can potentially generate the same effect. Thus, understanding the mechanisms allows the design to be more easily adapted and tested in other contexts even when some design features are not available, thus enhancing the adaptability, sustainability, and potential for scalability of the PD design.

3) Identifying affordances of MRS

This study showed the affordances of MRS for PD beyond an 'exercise machine' to drill techniques. In this study, MRS supported teachers to develop adaptive expertise in complex situations that require professional judgement rather than delivery of a technique alone. This study produced ten guiding principles when using MRS for PD:

1) Position MRS as one component of the whole ecosystem of PD, choose an evidence-based instructional design framework (e.g., Teaching for Understanding) and interweave MRS into the fabric of the instructional design.
2) Ensure MRS scenarios are close to teachers' context of practice (e.g. age group, subject).
3) Draw on the literature to script students' ideas (e.g., typical student alternative conceptions).
4) Foreground the most relevant aspects of the learning goal in the simulation (e.g., minimising classroom management if it is not the focus of the learning for the session).
5) Consider the context, needs of participants, and learning goals to determine the participant structure of the simulation (e.g., individual sessions, co-teaching sessions).
6) Combine fast thinking in the simulation with slow thinking after the simulation (e.g., provide teachers time for reflection and feedback after the simulation.)
7) Situate teachers' learning at the edge of their competency and make sure the scenarios are just challenging enough for teachers to make progress.
8) Leverage interleaved practice to support teachers in developing sensitivity in various situations.
9) Ensure skilful acting of the simulation specialist, preferably with knowledge about teaching and the culture.
10) Work closely with the practitioners at every step to ensure the relevance, cultural sensitivity and appropriateness of the MRS scenarios.

9.2.2 Methodological contributions

This study contributed to the DBR research method by adopting Sandoval's (2014) conjecture mapping and engaging in systematic design and research, addressing concerns about the rigour of DBR. This study showed that the DBR could fulfil its dual commitment of instructional design and theory building by specifying complex relations between design features, mediating processes and outcomes. This study also illustrated the flexibility of DBR that allows researchers and practitioners to design and adapt on the fly during the implementation process to test new design features and conjectures. Such flexibility and agile co-design enhance the ecological validity of the design and increase the chance that the design product will function well in its intended context.

This study made a methodological contribution to the analysis of classroom talk by constructing a coding scheme according to dialogic functions based on Wegerif's (2010) notion of dialogic space. In this coding scheme, a class discussion is conceptualised as a potential dialogic space, and teachers' responses are coded based on their dialogic function, i.e., widening, deepening, maintaining, and shaping the dialogic space as well as initiating and providing feedback (For the full coding scheme see Appendix 2). The rationale of constructing a coding scheme according to the dialogic function is to shift away from the form of the talk to emphasise the function that the teacher's third turn plays in the discussion. The reason is that talk could appear dialogic in form, but not dialogic in spirit (Boyd & Markarian, 2011). This coding framework is built on Wegerif's notion of dialogic space and instantiates what it means to improve dialogue in a classroom collectively,—de-identifying from the individuals (often resulting in disputational talk) or the group (often resulting in an accumulative talk), and instead identifying with the dialogue (fostering exploratory talk) (Mercer & Wegerif, 2004). This coding framework is theoretically coherent with Bakhtin's (1986) dialogism, viewing dialogue as relations rather than mediations (Wegerif, 2008). Future studies could further refine the coding scheme and test it on various types of dialogues in different classroom settings and subject areas.

9.2.3 Contributions to practice

1) **Four workshops sessions to support teachers in leading productive dialogic science discussions**

The study produced four workshops co-designed by practitioners and a researcher based on the Teaching for Understanding (TfU) instructional design framework to improve teachers' contingent responsiveness during dialogic science discussions. The four workshops cover a variety of topics including 1) ground rules and classroom culture, 2) elicitation discussion and talk moves, 3) consolidation discussion and sense-making, and 4) explanation discussion and advancing student thinking . The design of the workshops could serve as a prototype to be tested in other settings of teacher learning and subject areas.

2) **Four simulation scenarios:**

This study produced four simulation scenarios for four types of discussion with increasing complexity, accompanied by detailed scripts for the simulation specialists and simulation preparation guides for the teachers. The themes of the four simulations match the workshops: 1) negotiating ground rules; 2) elicitation discussion, 3) consolidation discussion, and 4) explanation discussion. Scripting of each scenario and the design of the simulation were grounded in literature and improved with teachers' feedback across four iterations. These scenarios and simulation sessions could be adapted and used for PD and teacher education programmes in various settings and cultural contexts.

3) **Shifting the metaphor of talk moves from tools to dialogic functions to support the advancement of student thinking**

This study addressed the limitations in Michaels and O'Connor's (2015) conceptualisation of talk moves based on Vygotsky's (1978) work on tools as mediational means. Shifting from the metaphor of 'tools' into a metaphor of a 'dialogic space', this study proposed to support teachers to advance student thinking during a dialogic discussion by organising talk moves according to their dialogic functions. In other words, during a discussion, the teacher's role is not to use tools for a particular goal or to address a particular challenge, but rather to widen, deepen, maintain, and shape the dialogic space. The metaphor of widening, deepening, maintaining, and shaping a dialogic space makes it intuitive for teachers to apply the appropriate move amongst the dynamic flow of classroom talk. Furthermore, the metaphor of dialogic space allows teachers to de-identify from individual ideas and identify with the whole dialogue to collectively improve the dialogue together, thus advancing student thinking. In this study, there was evidence that teachers could relate to the metaphor of a dialogic space[13] and adopted the language of opening, widening, deepening, maintaining, and shutting down the dialogic space when reasoning about their practice. However, it is unclear whether student thinking is in fact advanced when teachers adopt this conceptualisation of talk moves. Therefore, further studies are needed to test the affordances of this new conceptualisation of talk moves in teaching practice.

[13] Dialogic space was introduced as sense-making space in the PD to emphasise the scientific practice of sense-making.

9.3 Recommendations

Based on this study, I suggest the following recommendations for teacher educators, technology developers, researchers, and policymakers:

For teacher educators, this study suggested a multi-pronged approach to PD, encompassing all aspects of dialogic teaching, i.e., relational, improvisational, technical, contexual, and intellectual. The work also highlighted the importance of co-designing with practitioners and leveraging their ground-level wisdom in designing PD programmes that are contextualised and effective. For researchers, this study illustrated the affordances of a DBR approach to produce usable knowledge for practice and advance learning theory, and the importance of moving beyond testing 'what works', but to understand 'how it works', enhancing the adaptability, sustainability, and potential of scalability of the PD programme. For technology developers and policymakers, the findings reinforced the fact that technology does not have agency on its own and it is not a panacea to address challenges in education. The development of educational technology should be grounded in theoretically sound and evidence-based principles in collaboration with practitioners for their local contexts. Therefore, it is crucial to work with practitioners and study the affordances and limitations of technologies in the LMIC contexts.

9.4 Dissemination and next steps

The results of the study will be shared with practitioners (i.e., teachers, teacher coordinators, teacher educators, and school leaders), technology developers, and academic researchers. The next step is to conduct a follow-up study on the sustainability of teachers' learning. The school leader and I are planning to meet over the summer to design a PD programme building on what we learned in this study. Furthermore, the results of the study and teacher feedback will be shared with the technology developer (i.e., Mursion) to suggest areas of improvement. I will also disseminate the study through academic conferences. My submissions were accepted by the EARLI SIG 20-26 Conference in Utrecht as well as the ADLD Conference (Advancing (Digital) Learning Discourse in Teaching, Teacher Education, and Teachers' Professional Development) in Switzerland, which I will attend in September. My plan is also to make submissions to the upcoming conferences: BERA (British Educational Research Association), AERA, (American Educational Association) ISLS (International Society of the Learning Sciences). My supervisors and I will draw on the thesis to write multiple papers and submit them to relevant academic journals. Five potential papers were identified in this thesis: 1) the dialogic function coding scheme,

2) DBR study for PD and development of learning theory, 3) the affordances of MRS for PD in dialogic teaching, 4) a theoretical paper on the notion of CR, 5) a literature review on various conceptualisation of dialogic science teaching. In my postdoctoral work, I would like to continue refining the learning theory of CR and PD design across various educational and cultural contexts.

9.5 Doctoral study as a dialogue

I used metaphors across this thesis and illustrated the importance of how metaphors shape our conceptions and understanding. Doctoral study is often described with the metaphor of a journey. Here, I would like to use the metaphor of dialogue to reflect on my doctoral experience. Looking back at my PhD, I find myself engaging in dialogue with multiple voices.

The first voices were from my supervisors. I had the privilege to be mentored by two knowledgeable and extremely well-established scholars in the field, who modelled to me what dialogic teaching means. The supervisions were dialogues for thinking together. Instead of giving me the answers, they engaged in dialogue with me to explore ideas. The second dialogue I had was with teachers. Teaching is not something you do for other people, rather it is an ongoing dialogue between the two parties, each bringing their own unique experiences and ideas. I realised what Wegerif's chiasm means as I engage in ongoing dialogue with the teachers. The importance of a dialogue is not about reaching a conclusion, coming to a consensus, or departing in disagreement, rather it is the augmentation of both perspectives, a creative leap forward. The creative leap happened throughout this study, leaving me with notions and conceptualisation that I did not start with.

The third dialogue was with my peers. It was the safety of the dialogic space, the playfulness of ideas, the openness we feel towards each other, and the fact that we could just think out loud without worrying about any judgement that kindled the sparks of creativity and fueled new ideas. The fourth dialogue I had was with papers and books. At the beginning of my PhD, everything that was written on paper assumed a kind of authority and a sense of correctness, making me want to take what it says as the truth and agree with it. Interestingly, I noticed a change in my stance over time. I now read papers as if I am in dialogue with the authors and also see papers in dialogue with each other. Papers are living voices that I can respond to rather than engraved truth that I need to agree with, becoming an internally persuasive dialogue rather than an authoritative voice. As I become familiar with the research space and attend more conferences, I also become part of the dialogue. Finally, throughout my thesis, I often engaged in dialogue with myself. I asked myself questions and respond as I think and write. What could have I done better? Are you sure about this method? What does the response pattern mean?

At the start of my PhD, I came across Kenneth Burke's (1974) unending conversation, which I thought was a great depiction of academia. Re-reading Burke’s parlour today, I notice that it carries a sense of contention, debate and argumentation, which I think could be more productive if rewritten with the metaphor of dialogue. Here, I attempt to reframe Burke’s parlour into a dialogue to summarise my doctoral experience.

> Imagine that you enter a parlour. You come late. When you arrive, others have long preceded you, and they are engaged in a dialogue, a dialogue that is too vast for anyone to summarise concisely for you. In fact, the dialogue had already begun long before any of them got there, so that no one present is qualified to retrace for you all the steps that had gone before. You listen for a while, hearing different voices resonate, clash, and merge, and all of the sudden, it all clicked together and you have a spark of ideas, and then you put in your oar. Someone agrees, together you elaborate your ideas further. Someone disagrees, but you are not taking it personally, rather you try to understand why they disagree and the perspectives they come from. As the dialogue goes on, the questions are reframed, the assumptions are challenged, more perspectives entered the dialogic space, and the dialogue gets better and better. The dialogue is interminable. The hour grows late, you must depart. And you do depart, with the discussion still vigorously in progress and you find yourself with an enhanced perspective, an augmented view than you first entered the parlour (Adapted from Burke, 1974, pp. 110–111).

As I finish up my doctoral study, I have a deeper appreciation of the research on dialogue, not just as a research field, but also as a way of being. I feel a strong sense of inclusiveness that I am part of the ongoing dialogue in a community of researchers, part of the dialogue to improve teacher learning, and part of the past, present and future, and ultimately the larger dialogue to do good in the world.

References

Aguiar, O. G., Mortimer, E. F., & Scott, P. (2010). Learning from and responding to students' questions: The authoritative and dialogic tension. *Journal of Research in Science Teaching, 47*(2), 174–193. https://doi.org/10.1002/tea.20315

Ahmad, I., Ur Rehman, K., Ali, A., Khan, I., & Khan, F. A. (2014). Critical Analysis of the Problems of Education in Pakistan: Possible Solutions. *International Journal of Evaluation and Research in Education (IJERE)*, *3*(2), 79–84. https://doi.org/10.11591/ijere.v3i2.1805

Akera, A. (2007). Constructing a Representation for an Ecology of Knowledge: Methodological Advances in the Integration of Knowledge and Its Various Contexts. *Social Studies of Science*, *37*(3), 413–441.

Alexander, R. (2017). *Towards dialogic teaching: Rethinking classroom talk* (Fifth edition.). Dialogos.

Alexander, R. (2020). *A Dialogic Teaching Companion* (1st ed.). Routledge. https://doi.org/10.4324/9781351040143

Alvermann, D. E., & Hayes, D. A. (1989). Classroom Discussion of Content Area Reading Assignments: An Intervention Study. *Reading Research Quarterly*, *24*(3), 305–335.

Amir, S., Nowshaba, S., Rizwan, A., & Hasan, A. (2020). *Pakistan's Education System: An Analysis of Education Policies and Drawbacks*.

Andrabi, T., & Das, J. (2002). *The rise of private schooling in Pakistan: Catering to the urban elite or educating the rural poor?*

Andrist, S., Collier, W., Gleicher, M., Mutlu, B., & Shaffer, D. (2015). Look together: Analyzing gaze coordination with epistemic network analysis. *Frontiers in Psychology*, *6*. https://doi.org/10.3389/fpsyg.2015.01016

Appleton, K. (2003). How Do Beginning Primary School Teachers Cope with Science? Toward an Understanding of Science Teaching Practice. *Research in Science Education*, *33*(1), 1–25. https://doi.org/10.1023/A:1023666618800

Bakhtin, M. (1986). *Speech genres and other late essays*. University of Texas.

Bakhtin, M. M. (1981). *The Dialogic Imagination: Four Essays* (M. Holquist, Ed.; C. Emerson & M. Holquist, Trans.). University of Texas Press.

Bakker, A. (2018). *Design research in education: A practical guide for early career researchers*. Routledge.

Baldinger, E. E., & Munson, J. (2020). Developing adaptive expertise in the wake of rehearsals: An emergent model of the debrief discussions of non-rehearsing teachers. *Teaching and Teacher Education*, *95*, 103125. https://doi.org/10.1016/j.tate.2020.103125

Baldinger, E. M. (2017). "Maybe It's a Status Problem." Development of Mathematics Teacher Noticing for Equity. In E. O. Schack, M. H. Fisher, & J. A. Wilhelm (Eds.), *Teacher Noticing: Bridging and Broadening Perspectives, Contexts, and Frameworks* (pp. 231–249). Springer International Publishing. https://doi.org/10.1007/978-3-319-46753-5_14

Baloch, I., & Abeba Taddese. (2020). *EdTech in Pakistan: A Rapid Scan*. Zenodo. https://doi.org/10.5281/ZENODO.3911655

Banks, J. (Ed.). (1998). *Handbook of Simulation*. John Wiley & Sons, Inc. https://doi.org/10.1002/9780470172445

Barab, S., & Squire, K. (2004). Design-Based Research: Putting a Stake in the Ground. *Journal of the Learning Sciences*, *13*(1), 1–14. https://doi.org/10.1207/s15327809jls1301_1

Barnes, D. (1976). *From Communication to Curriculum*. Peguin Books Ltd.

Barshay, J. (2018). 20 judgments a teacher makes in 1 minute and 28 seconds. *The Hechinger Report*. https://hechingerreport.org/20-judgments-a-teacher-makes-in-1-minute-and-28-seconds/

Bautista, N. U., & Boone, W. J. (2015). Exploring the Impact of TeachME™ Lab Virtual Classroom Teaching Simulation on Early Childhood Education Majors' Self-Efficacy Beliefs. *Journal of Science Teacher Education*, *26*(3), 237–262. https://doi.org/10.1007/s10972-014-9418-8

Beg, S., Lucas, A. M., Halim, W., & Saif, U. (2020). *Tools for Teaching: Leveraging Technology to Improve Classroom Content Delivery*. 39.

Bereiter, C. (1994). Implications of postmodernism for science, or, science as progressive discourse. *Educational Psychologist*, *29*(1), 3–12. https://doi.org/10.1207/s15326985ep2901_1

Bereiter, C., & Scardamalia, M. (1993). *Surpassing Ourselves: An Inquiry Into the Nature and Implications of Expertise.* Open Court.

Bianchini, J. A. (1997). Where knowledge construction, equity, and context intersect: Student learning of science in small groups. *Journal of Research in Science Teaching*, *34*(10), 1039–1065. https://doi.org/10.1002/(SICI)1098-2736(199712)34:10<1039::AID-TEA5>3.0.CO;2-S

Biesta, G. (2007). Why "What Works" Won't Work: Evidence-Based Practice and the Democratic Deficit in Educational Research. *Educational Theory*, *57*(1), 1–22. https://doi.org/10.1111/j.1741-5446.2006.00241.x

Bondie, R., Jack, J., & Dede, C. (2019). Agile Thinking: Deciding to Teach Every Student. *Simulations in Teacher Education Conference Short Paper Submissions*. Simulations in Teacher Education Conference, Louisville, KY.

Bondie, R., Mancenido, Z., & Dede, C. (2021). Interaction principles for digital puppeteering to promote teacher learning. *Journal of Research on Technology in Education*, *53*(1), 107–123. https://doi.org/10.1080/15391523.2020.1823284

Borko, H. (2004). Professional Development and Teacher Learning: Mapping the Terrain. *Educational Researcher*, *33*(8), 3–15. https://doi.org/10.3102/0013189X033008003

Boyd, M. P., & Markarian, W. C. (2011). Dialogic teaching: Talk in service of a dialogic stance. *Language and Education*, *25*(6), 515–534. https://doi.org/10.1080/09500782.2011.597861

Boyd, M., & Rubin, D. (2006). How Contingent Questioning Promotes Extended Student Talk: A Function of Display Questions. *Journal of Literacy Research*, *38*(2), 141–169. https://doi.org/10.1207/s15548430jlr3802_2

Breadth, D. (2018, January 18). Newton was wrong. So was Einstein. And that's okay…. *Medium*. https://medium.com/@deepbreadth/newton-was-wrong-so-was-einstein-and-thats-okay-a5ad4dedfe26

Bressler, D. M., Bodzin, A. M., Eagan, B., & Tabatabai, S. (2019). Using Epistemic Network Analysis to Examine Discourse and Scientific Practice During a Collaborative Game. *Journal of Science Education and Technology*, *28*(5), 553–566. https://doi.org/10.1007/s10956-019-09786-8

British Educational Research Association [BERA]. (2018). *Ethical guidelines for educational research (BERA), fourth edition*. https://www.bera.ac.uk/researchers-resources/publications/ethical- guidelines-for-educational-research-2018

Brown, P. C., Roediger, H. L., & McDaniel, M. A. (2014). *Make It Stick—Peter C. Brown, Henry L. Roediger III, Mark A. McDaniel*. Harvard University Press. https://www.hup.harvard.edu/catalog.php?isbn=9780674729018

Bruner, J. S. (1996). *The Culture of Education*. Harvard University Press.

Buber, M. (1937). *I and thou* (R. G. Smith, Trans.). T. & T. Clark.

Buber, M. (2000). *I and Thou*. Simon & Schuster.

Burbules, N. C. (1993). *Dialogue in teaching: Theory and practice / Nicholas C. Burbules*. Teachers College Press.

Burke, K. (1974). *The Philosophy of Literary Form*.

Byrne, D. (2017). *Data analysis and interpretation*. https://methods.sagepub.com/project-planner/data-analysis-and-interpretation

Campbell, T., Schwarz, C., & Windschitl, M. (2016). What We Call Misconceptions May Be Necessary Stepping-Stones Toward Making Sense of the World. *The Science Teacher*, 6.

Cave, K. R., & Bichot, N. P. (1999). Visuospatial attention: Beyond a spotlight model. *Psychonomic Bulletin & Review*, *6*(2), 204–223. https://doi.org/10.3758/BF03212327

Cazden, C. B. (2001). *Classroom Discourse: The Language of Teaching and Learning. Second Edition*. Heinemann, 88 Post Road West, P.

Chan, K. K. H., Xu, L., Cooper, R., Berry, A., & van Driel, J. H. (2020). Teacher noticing in science education: Do you see what I see? *Studies in Science Education*, 1–44. https://doi.org/10.1080/03057267.2020.1755803

Chan, K. K. H., & Yau, K. W. (2020). Using Video-Based Interviews to Investigate Pre-service Secondary Science Teachers' Situation-Specific Skills for Informal Formative Assessment. *International Journal of Science and Mathematics Education*. https://doi.org/10.1007/s10763-020-10056-y

Chang, C. C. (2022). *Dialogic education, historical thinking and epistemic beliefs: A design-based research study of teaching in Taiwanese classrooms* [Thesis, University of Cambridge]. https://doi.org/10.17863/CAM.81232

Chazan, D., & Ball, D. (1999). Beyond being told not to tell. *For the Learning of Mathematics*, *19*(2), 2–10.

Chen, G., Chan, C. K. K., Chan, K. K. H., Clarke, S. N., & Resnick, L. B. (2020a). Efficacy of video-based teacher professional development for increasing classroom discourse and student learning. *Journal of the Learning Sciences*, *29*(4–5), 642–680. https://doi.org/10.1080/10508406.2020.1783269

Chen, G., Chan, C. K. K., Chan, K. K. H., Clarke, S. N., & Resnick, L. B. (2020b). Efficacy of video-based teacher professional development for increasing classroom discourse and student learning. *Journal of the Learning Sciences*, *29*(4–5), 642–680. https://doi.org/10.1080/10508406.2020.1783269

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

Clarke, S. N., Howley, I., Resnick, L., & Penstein Rosé, C. (2016). Student agency to participate in dialogic science discussions. *Learning, Culture and Social Interaction*, *10*, 27–39. https://doi.org/10.1016/j.lcsi.2016.01.002

Cobb, P., Confrey, J., diSessa, A., Lehrer, R., & Schauble, L. (2003). Design Experiments in Educational Research. *Educational Researcher*, *32*(1), 9–13. https://doi.org/10.3102/0013189X032001009

Colley, C., & Windschitl, M. (2016). Rigor in Elementary Science Students' Discourse: The Role of Responsiveness and Supportive Conditions for Talk. *Science Education*, *100*(6), 1009–1038. https://doi.org/10.1002/sce.21243

Collins, A. (1992). Toward a Design Science of Education. In E. Scanlon & T. O'Shea (Eds.), *New Directions in Educational Technology* (pp. 15–22). Springer. https://doi.org/10.1007/978-3-642-77750-9_2

Collins, A., Joseph, D., & Bielaczyc, K. (2004). Design Research: Theoretical and Methodological Issues. *Journal of the Learning Sciences*, *13*(1), 15–42. https://doi.org/10.1207/s15327809jls1301_2

Collins, E. C., & Green, J. L. (1990). Metaphors: The construction of a perspective. *Theory Into Practice*, *29*(2), 71–77. https://doi.org/10.1080/00405849009543435

Dalinger, T., Thomas, K. B., Stansberry, S., & Xiu, Y. (2020). A mixed reality simulation offers strategic practice for pre-service teachers. *Computers and Education*, *144*. Scopus. https://doi.org/10.1016/j.compedu.2019.103696

Dawes, L., Mercer, N., & Wegerif, R. (2000). *Thinking together: A programme of activities for developing thinking skills at KS2*. Questions Publishing Company.

Dawson, M. R., & Lignugaris/Kraft, B. (2017). Meaningful Practice: Generalizing Foundation Teaching Skills From TLE TeachLivE™ to the Classroom. *Teacher Education and Special Education*, *40*(1), 26–50. https://doi.org/10.1177/0888406416664184

Dede, C. (2009). Immersive interfaces for engagement and learning. *Science*, *323*(5910), 66–69. https://doi.org/10.1126/science.1167311

Dent-Read, C. H., & Szokolszky, A. (1993). Where Do Metaphors Come From? *Metaphor and Symbolic Activity*, *8*(3), 227–242. https://doi.org/10.1207/s15327868ms0803_8

Dieker, L. A., Rodriguez, J. A., Lignugaris/Kraft, B., Hynes, M. C., & Hughes, C. E. (2013). The Potential of Simulated Environments in Teacher Education: Current and Future Possibilities. *Teacher Education and Special Education*. https://doi.org/10.1177/0888406413512683

Dieker, L., Hughes, C., & Hynes, M. (2016). *Bill & Melinda Gates Foundation Final Report: UCF TLE TeachLivE*. University of Central Florida. http://teachlive.org/wp-content/uploads/2016/09/Gates-Foundation-Final-Report8_27_2016.pdf

Dieker, L., Rodriguez, J., Lignugaris-Kraft, B., Hynes, M., & Hughes, C. (2014). The Potential of Simulated Environments in Teacher Education: Current and Future Possibilities. *Teacher Education and Special Education The Journal of the Teacher Education Division of the Council for Exceptional Children*, *37*(1), 21–33. https://doi.org/10.1177/0888406413512683

diSessa, A. (2000). *Changing Minds: Computers, Learning, and Literacy*. A Bradford Book.

Doubler, S., & Paget, K. F. (2016). Professional Learning with Web-Based Videos: The Talk Science Experience. In C. Dede, A. Eisenkraft, K. Frumin, & A. Hartley, *Teacher Learning in the Digital Age: Online Professional Development in STEM Education* (pp. 33–49). Harvard Education Press.

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

Driver, R., Squires, A., Rushworth, P., & Wood-Robinson, V. (2014). *Making Sense of Secondary Science: Research into children's ideas* (2nd ed.). Routledge. https://doi.org/10.4324/9781315747415

Dudley, P. (2013). Teacher learning in Lesson Study: What interaction-level discourse analysis revealed about how teachers utilised imagination, tacit knowledge of teaching and fresh evidence of pupils learning, to develop practice knowledge and so enhance their pupils' learning. *Teaching and Teacher Education*, *34*, 107–121. https://doi.org/10.1016/j.tate.2013.04.006

Duschl, R. A., & Osborne, J. (2002). Supporting and Promoting Argumentation Discourse in Science Education. *Studies in Science Education*, *38*(1), 39–72. https://doi.org/10.1080/03057260208560187

Duschl, R. A., Schweingruber, H. A., & Shouse, A. W. (Eds.). (2007). *Taking Science to School: Learning and Teaching Science in Grades K-8*. The national Academies Press. https://doi.org/10.17226/11625

Dyer, E. B., & Sherin, M. G. (2016). Instructional reasoning about interpretations of student thinking that supports responsive teaching in secondary mathematics. *ZDM*, *48*(1), 69–82. https://doi.org/10.1007/s11858-015-0740-1

Edwards, A., & Westgate, D. P. G. (1994). *Investigating Classroom Talk* (2nd ed.). UK The Falmer Press.

Empson, S., & Jacobs, V. (2008). *Learning to Listen to Children's Mathematics* (pp. 257–281).

Erickson, F. (2010). On Noticing Teacher Noticing. In *Mathematics Teacher Noticing*. Routledge.

Eriksen, C. W., & St. James, J. D. (1986). Visual attention within and around the field of focal attention: A zoom lens model. *Perception & Psychophysics*, *40*(4), 225–240. https://doi.org/10.3758/BF03211502

Ersozlu, Z., Ledger, S., Ersozlu, A., Mayne, F., & Wildy, H. (2021). Mixed-Reality Learning Environments in Teacher Education: An Analysis of TeachLivE™ Research. *SAGE Open*, *11*(3).

Escobar, A. (1995). *Encountering Development: The Making and Unmaking of the Third World* (STU-Student edition). Princeton University Press. https://www.jstor.org/stable/j.ctt7rtgw

Feuerstein, R., Klein, P., & Tannenbaum, A. (1991). Mediated learning experience. *Mediated Learning Experience. Theoretical, Psychological and Learning Implications*, 3–51.

Ford, M. J., & Forman, E. A. (2015). Uncertainty and Scientific Progress in Classroom Dialogue. In L. Resnick, C. Asterhan, & S. Clarke (Eds.), *Socializing Intelligence Through Academic Talk and Dialogue* (pp. 403–414). American Educational Research Association. http://ebookcentral.proquest.com/lib/cam/detail.action?docID=4866316

Ford, M. J., & Wargo, B. M. (2012). Dialogic framing of scientific content for conceptual and epistemic understanding. *Science Education*, *96*(3), 369–391. https://doi.org/10.1002/sce.20482

Fortes, G., & De Brasi, L. (2022). *Employing the intellectual virtues to better understand argumentation interventions*. EARLI SIG 20-26 Joint Conference, Utretcht.

Freire, P. (1970). *Pedagogy of the oppressed* (M. B. Ramos, Trans.). New York : Herder and Herder.

Freire, P. (2000). *Pedagogy of the oppressed*. Continuum.

Fujita, T., Doney, J., Flanagan, R., & Wegerif, R. (2021). Collaborative group work in mathematics in the UK and Japan: Use of group thinking measure tests. *Education 3-13*, *49*(2), 119–133. https://doi.org/10.1080/03004279.2019.1701513

Gadamer, H.-G. (1975). Hermeneutics and Social Science. *Cultural Hermeneutics*, *2*(4), 307–316. https://doi.org/10.1177/019145377500200402

Gamoran Sherin, M., & van Es, E. A. (2009). Effects of Video Club Participation on Teachers' Professional Vision. *Journal of Teacher Education*, *60*(1), 20–37. https://doi.org/10.1177/0022487108328155

Gee, J. P. (2003). What video games have to teach us about learning and literacy. *Computers in Entertainment*, *1*(1), 20. https://doi.org/10.1145/950566.950595

Geraets, A. A., Nottolini, I. L., Doty, C. M., Wan, T., Chini, J. J., & Saitta, E. K. H. (2021). Preparing GTAs for Active Learning in the General Chemistry Lab: Development of an

Evidence-Based Rehearsal Module for a Mixed-Reality Teaching Simulator. *Journal of Science Education and Technology*, *30*(6), 829–840.

Gibson, J. J. (2014). *The Ecological Approach to Visual Perception: Classic Edition* (1st edition). Routledge.

Gillies, R. M., Nichols, K., Burgh, G., & Haynes, M. (2014). Primary students' scientific reasoning and discourse during cooperative inquiry-based science activities. *International Journal of Educational Research*, *63*, 127–140. https://doi.org/10.1016/j.ijer.2013.01.001

Glass, A. L. (2016). *Cognition: A Neuroscience Approach*. Cambridge University Press.

Gopnik, A., Meltzoff, A. N., & Kuhl, P. K. (2001). *The scientist in the crib: What early learning tells us about the mind* (1st perennial ed). Harper.

Grant, M., & Ferguson, S. (2021). Virtual Microteaching, Simulation Technology & Curricula: A Recipe for Improving Prospective Elementary Mathematics Teachers' Confidence and Preparedness. *Journal of Technology and Teacher Education*, *29*(2), 137–164.

Gravemeijer, K. P. E., & Cobb, P. (2006). Design research from a learning design perspective. In J. Akker, K. Gravemeijer, S. McKenney, & N. Nieveen (Eds.), *Educational Design Research* (pp. 45–85). Taylor and Francis Ltd.

Grinath, A. S., & Southerland, S. A. (2019). Applying the ambitious science teaching framework in undergraduate biology: Responsive talk moves that support explanatory rigor. *Science Education*, *103*(1), 92–122. https://doi.org/10.1002/sce.21484

Gröschner, A., Seidel, T., Kiemer, K., & Pehmer, A.-K. (2015). Through the lens of teacher professional development components: The 'Dialogic Video Cycle' as an innovative program to foster classroom dialogue. *Professional Development in Education*, *41*(4), 729–756. https://doi.org/10.1080/19415257.2014.939692

Gröschner, A., Seidel, T., Pehmer, A.-K., & Kiemer, K. (2014). Facilitating collaborative teacher learning: The role of "mindfulness" in video-based teacher professional development programs. *Gruppendynamik Und Organisationsberatung*, *45*(3), 273–290. https://doi.org/10.1007/s11612-014-0248-0

Grossman, P. (2018). Teaching Core Practices in Teacher Education. In *Harvard Education Press*. Harvard Education Press.

Grossman, P., Compton, C., Igra, D., Ronfeldt, M., Shahan, E., & Williamson, P. W. (2009). Teaching Practice: A Cross-Professional Perspective. *Teachers College Record*, *111*(9), 2055–2100. https://doi.org/10.1177/016146810911100905

Grossman, P., Hammerness, K., & McDonald, M. (2009). Redefining teaching, re-imagining teacher education. *Teachers and Teaching*, *15*(2), 273–289. https://doi.org/10.1080/13540600902875340

Grotzer, T. A. (2002). Expanding Our Vision for Educational Technology: Procedural, Conceptual, and Structural Knowledge. *Educational Technology*, *42*(2), 52–59.

Grotzer, T. A., & Basca, B. B. (2003). How does grasping the underlying causal structures of ecosystems impact students' understanding? *Journal of Biological Education*, *38*(1), 16–29. https://doi.org/10.1080/00219266.2003.9655891

Grotzer, T. A., Kamarainen, A. M., Tutwiler, M. S., Metcalf, S., & Dede, C. (2013). Learning to Reason about Ecosystems Dynamics over Time: The Challenges of an Event-Based Causal Focus. *BioScience*, *63*(4), 288–296. https://doi.org/10.1525/bio.2013.63.4.9

Gundel, E., & Piro, J. S. (2021). Perceptions of Self-Efficacy in Mixed Reality Simulations. *Action in Teacher Education*, *43*(2), 176–194.

Gundel, E., Piro, J. S., Straub, C., & Smith, K. (2019). Self-Efficacy in Mixed Reality Simulations: Implications for Preservice Teacher Education. *The Teacher Educator*, *54*(3), 244–269. https://doi.org/10.1080/08878730.2019.1591560

Hardman, J. (2019). Developing and supporting implementation of a dialogic pedagogy in primary schools in England. *Teaching and Teacher Education*, *86*, 102908. https://doi.org/10.1016/j.tate.2019.102908

Harris, C. J., Phillips, R. S., & Penuel, W. R. (2012). Examining Teachers' Instructional Moves Aimed at Developing Students' Ideas and Questions in Learner-Centered Science Classrooms. *Journal of Science Teacher Education*, *23*(7), 769–788. https://doi.org/10.1007/s10972-011-9237-0

Haßler, B., Hennessy, S., Cross, A., Chileshe, E., & Machiko, B. (2015). School-based professional development in a developing context: Lessons learnt from a case study in Zambia. *Professional Development in Education*, *41*(5), 806–825. https://doi.org/10.1080/19415257.2014.938355

Hatano, G., & Inagaki, K. (1986). Two Course of Expertise. In H. W. (Harold W. Stevenson, K. Hakuta, & H. Azuma (Eds.), *Child development and education in Japan*. W.H. Freeman.

Hatano, G., & Oura, Y. (2003). Commentary: Reconceptualizing School Learning Using Insight From Expertise Research. *Educational Researcher*, *32*(8), 26–29. https://doi.org/10.3102/0013189X032008026

Hattie, J., & Timperley, H. (2007). The Power of Feedback. *Review of Educational Research*, *77*(1), 81–112. https://doi.org/10.3102/003465430298487

Hennessy, S., Calcagni, E., Leung, A., & Mercer, N. (2021). An analysis of the forms of teacher-student dialogue that are most productive for learning. *Language and Education*, *0*(0), 1–26. https://doi.org/10.1080/09500782.2021.1956943

Hennessy, S., D'Angelo, S., McIntyre, N., Koomar, S., Kreimeia, A., Cao, L., Brugha, M., & Zubairi, A. (2022). Technology Use for Teacher Professional Development in Low- and Middle-Income Countries: A Systematic Review. *Computers and Education Open*, 100080. https://doi.org/10.1016/j.caeo.2022.100080

Hennessy, S., & Davies, M. (2020). Teacher Professional Development to Support Classroom Dialogue: Challenges and Promises. In N. Mercer, R. Wegerif, & L. Major (Eds.), *The Routledge international handbook of research on dialogic education* (pp. 238–253). Routledge.

Hennessy, S., Dragovic, T., & Warwick, P. (2018). A research-informed, school-based professional development workshop programme to promote dialogic teaching with interactive technologies. *Professional Development in Education*, *44*(2), 145–168. https://doi.org/10.1080/19415257.2016.1258653

Hennessy, S., Haßler, B., & Hofmann, R. (2015a). Challenges and opportunities for teacher professional development in interactive use of technology in African schools. *Technology, Pedagogy and Education*, *24*(5), 1–28. https://doi.org/10.1080/1475939X.2015.1092466

Hennessy, S., Haßler, B., & Hofmann, R. (2015b). Challenges and opportunities for teacher professional development in interactive use of technology in African schools. *Technology, Pedagogy and Education*, *24*(5), 1–28. https://doi.org/10.1080/1475939X.2015.1092466

Hennessy, S., Haßler, B., & Hofmann, R. (2016). Pedagogic change by Zambian primary school teachers participating in the OER4Schools professional development programme for one year. *Research Papers in Education*, *31*(4), 399–427. https://doi.org/10.1080/02671522.2015.1073343

Hennessy, S., Kershner, R., Calcagni, E., & Ahmed, F. (2021). Supporting practitioner-led inquiry into classroom dialogue with a research-informed professional learning resource: A design-based approach. *Review of Education*, *9*(3), e3269. https://doi.org/10.1002/rev3.3269

Hennessy, S., Mercer, N., & Warwick, P. (2011). A Dialogic Inquiry Approach to Working with Teachers in Developing Classroom Dialogue. *Teachers College Record*, *113*(9), 1906–1959. https://doi.org/10.1177/016146811111300902

Hennessy, S., Rojas-Drummond, S., Higham, R., Márquez, A. M., Maine, F., Ríos, R. M., García-Carrión, R., Torreblanca, O., & Barrera, M. J. (2016). Developing a coding scheme for analysing classroom dialogue across educational contexts. *Learning, Culture and Social Interaction*, *9*, 16–44. https://doi.org/10.1016/j.lcsi.2015.12.001

Herrington, J. A., McKenney, S., Reeves, T. C., & Oliver, R. (2007). Design-based research and doctoral students: Guidelines for preparing a dissertation proposal. *Proceedings of EdMedia 2007: World Conference on Educational Multimedia, Hypermedia & Telecommunications*, 4089–4097.

Herrington, J., McKenney, S., Reeves, T. C., & Oliver, R. (2007). Design-based research and doctoral students: Guidelines for preparing a dissertation proposal. *Proceedings of World Conference on Educational Multimedia, Hypermedia and Telecommunications 2007*, 4089–4097. https://research.utwente.nl/en/publications/design-based-research-and-doctoral-students-guidelines-for-prepar

Hofmann, R. (2020). Dialogue, teachers and professional development. In N. Mercer, R. Wegerif, & L. Major (Eds.), *The Routledge International Handbook of Research on Dialogic Education* (pp. 213–216). Routledge. https://doi.org/10.4324/9780429441677-18

Hogan, K., Nastasi, B. K., & Pressley, M. (1999). Discourse Patterns and Collaborative Scientific Reasoning in Peer and Teacher-Guided Discussions. *Cognition and Instruction*, *17*(4), 379–432. https://doi.org/10.1207/S1532690XCI1704_2

Howe, & Abedin, M. (2013). Classroom dialogue: A systematic review across four decades of research. *Cambridge Journal of Education*, *43*(3), 325–356. Scopus. https://doi.org/10.1080/0305764X.2013.786024

Howe, C., Hennessy, S., Mercer, N., Vrikki, M., & Wheatley, L. (2019). Teacher–Student Dialogue During Classroom Teaching: Does It Really Impact on Student Outcomes? *Journal of the Learning Sciences*, *28*(4–5), 462–512. https://doi.org/10.1080/10508406.2019.1573730

Howe, C., & Mercer, N. (2017). Commentary on the papers. *Language and Education*, *31*(1), 83–92. https://doi.org/10.1080/09500782.2016.1230126

Huang, Y., Miller, K., Cortina, K., & Richter, D. (2021). Teachers' professional vision in action: Comparing expert and novice teacher's real-life eye movements in the classroom.

Zeitschrift Für Pädagogische Psychologie, *2021*, 1–18. https://doi.org/10.1024/1010-0652/a000313

Hudson, M. E. (2021). Is Practice in a Mixed-Reality Environment Better than Role Play for Promoting Implementation Fidelity of the Constant Time Delay Procedure for Special Education Undergraduates? *Journal of the American Academy of Special Education Professionals*, 59–72.

Hudson, M. E., Voytecki, K. S., Owens, T. L., & Zhang, G. (2019). Preservice Teacher Experiences Implementing Classroom Management Practices Through Mixed-Reality Simulations. *Rural Special Education Quarterly*, *38*(2), 79–94. https://doi.org/10.1177/8756870519841421

Inquiry Project. (2011). *Overview of Grade 5 Curriculum.* https://inquiryproject.terc.edu/curriculum/curriculum5/index.html

Inquiry Project/Talk Science. (2012). *Four Discussion Types.* https://inquiryproject.terc.edu/shared/pd/cc/DiscussionTypes.pdf

Kahneman, D. (1973). *Attention and Effort.* Prentice-Hall.

Kahneman, D. (2013). *Thinking, Fast and Slow* (Reprint edition). Macmillan USA.

Kaiser, G., Busse, A., Hoth, J., König, J., & Blömeke, S. (2015). About the Complexities of Video-Based Assessments: Theoretical and Methodological Approaches to Overcoming Shortcomings of Research on Teachers' Competence. *International Journal of Science and Mathematics Education*, *13*(2), 369–387. https://doi.org/10.1007/s10763-015-9616-7

Kalinec-Craig, C. (2017). "Everything Matters": Mexican-American Prospective Elementary Teachers Noticing Issues of Status and Participation While Learning to Teach Mathematics. In E. O. Schack, M. H. Fisher, & J. A. Wilhelm (Eds.), *Teacher Noticing: Bridging and Broadening Perspectives, Contexts, and Frameworks* (pp. 215–229). Springer International Publishing. https://doi.org/10.1007/978-3-319-46753-5_13

Kapon, S. (2017). Unpacking Sensemaking. *Science Education*, *101*(1), 165–198. https://doi.org/10.1002/sce.21248

Kaufman, D., & Ireland, A. (2016). Enhancing Teacher Education with Simulations. *TechTrends: Linking Research & Practice to Improve Learning*, *60*(3), 260–267. https://doi.org/10.1007/s11528-016-0049-0

Kavanagh, S. S., Conrad, J., & Dagogo-Jack, S. (2020). From rote to reasoned: Examining the role of pedagogical reasoning in practice-based teacher education. *Teaching and Teacher Education*, *89*. https://doi.org/10.1016/j.tate.2019.102991

Kazak, S., Wegerif, R., & Fujita, T. (2015). Combining scaffolding for content and scaffolding for dialogue to support conceptual breakthroughs in understanding probability. *ZDM*, *47*(7), 1269–1283. https://doi.org/10.1007/s11858-015-0720-5

Keller, L., Cortina, K. S., Müller, K., & Miller, K. F. (2022). Noticing and weighing alternatives in the reflection of regular classroom teaching: Evidence of expertise using mobile eye-tracking. *Instructional Science*, *50*(2), 251–272. https://doi.org/10.1007/s11251-021-09570-5

Kelly, A. (2004). Design Research in Education: Yes, but Is It Methodological? *The Journal of the Learning Sciences*, *13*(1), 115–128. JSTOR.

Kelly, G. J. (2007). Discourse in science classrooms. In K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education* (Vol. 1, pp. 443–469).

Kelly, G. J., Brown, C., & Crawford, T. (2000). Experiments, contingencies, and curriculum: Providing opportunities for learning through improvisation in science teaching. *Science Education*, *84*(5), 624–657. https://doi.org/10.1002/1098-237X(200009)84:5<624::AID-SCE5>3.0.CO;2-S

Khoja-Moolji, S. (2017). Pedagogical (Re)Encounters: Enacting a Decolonial Praxis in Teacher Professional Development in Pakistan. *Comparative Education Review*, *61*(S1), S146–S170. https://doi.org/10.1086/690298

Kind, V., & Chan, K. K. H. (2019). Resolving the amalgam: Connecting pedagogical content knowledge, content knowledge and pedagogical knowledge. *International Journal of Science Education*, *41*(7), 964–978. https://doi.org/10.1080/09500693.2019.1584931

Kind, V., Park, S., & Chan, K. K. H. (2022). Science Teacher Professional Knowledge and Its Relationship to High-Quality Science Instruction. In *Handbook of Research on Science Teacher Education*. Routledge.

Kleinknecht, M., & Gröschner, A. (2016). Fostering preservice teachers' noticing with structured video feedback: Results of an online- and video-based intervention study. *Teaching and Teacher Education*, *59*, 45–56. https://doi.org/10.1016/j.tate.2016.05.020

Knight, S., & Mercer, N. (2015). The role of exploratory talk in classroom search engine tasks. *Technology, Pedagogy and Education*, *24*(3), 303–319. https://doi.org/10.1080/1475939X.2014.931884

König, J., Blömeke, S., Klein, P., Suhl, U., Busse, A., & Kaiser, G. (2014). Is teachers' general pedagogical knowledge a premise for noticing and interpreting classroom situations? A video-based assessment approach. *Teaching and Teacher Education*, *38*, 76–88. https://doi.org/10.1016/j.tate.2013.11.004

König, J., & Kramer, C. (2016). Teacher professional knowledge and classroom management: On the relation of general pedagogical knowledge (GPK) and classroom management expertise (CME). *ZDM*, *48*(1), 139–151. https://doi.org/10.1007/s11858-015-0705-4

Krippendorff, K. (2019). *Content Analysis: An Introduction to Its Methodology*. SAGE Publications, Inc. https://doi.org/10.4135/9781071878781

Lagemann, E. C. (2002). *An elusive science: The troubling history of education research*. University of Chicago Press. https://www.press.uchicago.edu/ucp/books/book/chicago/E/bo3683209.html

Lakoff, G., & Johnson, M. (1980). *Metaphors we live by*. University of Chicago Press.

Lampert, M. (1985). How Do Teachers Manage to Teach? Perspectives on Problems in Practice. *Harvard Educational Review*, *55*(2), 178–195.

Lau, M. (2010). *Understanding the dynamics of teacher attention: Examples of how high school physics and physical science teachers attend to student ideas* [Ph.D., University of Maryland, College Park]. https://search.proquest.com/docview/762232632/abstract/6723D3270B654843PQ/1

Lee, C., Lee, T., Dickerson, D., Castles, R., & Vos, P. (2021). Comparison of Peer-to-Peer and Virtual Simulation Rehearsals in Eliciting Student Thinking through Number Talks. *Contemporary Issues in Technology and Teacher Education (CITE Journal)*, *21*(2).

Lefstein, A. (2008). Changing Classroom Practice Through the English National Literacy Strategy: A Micro-Interactional Perspective. *American Educational Research Journal*, *45*(3), 701–737. https://doi.org/10.3102/0002831208316256

Lefstein, A., Israeli, M., Pollak, I., & Bozo-Schwartz, M. (2013). Investigating dilemmas in teaching: Towards a new form of pedagogical scholarship. *Studia paedagogica*, *18*(4), Article 4. https://doi.org/10.5817/SP2013-4-2

Lefstein, A., Louie, N., Segal, A., & Becher, A. (2020). Taking stock of research on teacher collaborative discourse: Theory and method in a nascent field. *Teaching and Teacher Education*, *88*, 102954. https://doi.org/10.1016/j.tate.2019.102954

Lefstein, A., & Snell, J. (2013). *Better than Best Practice: Developing teaching and learning through dialogue*. Routledge. https://doi.org/10.4324/9781315884516

Lemke, J. L. (1990). *Talking science: Language, learning, and values*. Ablex Pub. Corp.

Lemov, D., Woolway, E., Yezzi, K., & Heath, D. (2012). *Practice Perfect: 42 Rules for Getting Better at Getting Better* (1 edition). Jossey-Bass.

Levin, D., Hammer, D., & Coffey, J. (2009). Novice Teachers' Attention to Student Thinking. *Journal of Teacher Education - J TEACH EDUC*, *60*, 142–154. https://doi.org/10.1177/0022487108330245

Lidz, C. S. (1991). *Practitioner's guide to dynamic assessment*. Guilford Press.

Lineback, J. E. (2015). The Redirection: An Indicator of How Teachers Respond to Student Thinking. *Journal of the Learning Sciences*, *24*(3), 419–460. https://doi.org/10.1080/10508406.2014.930707

Llobera, J., Sanchez-Vives, M. V., & Slater, M. (2013). The relationship between virtual body ownership and temperature sensitivity. *Journal of The Royal Society Interface*, *10*(85), 20130300. https://doi.org/10.1098/rsif.2013.0300

Louie, N. L. (2018). Culture and ideology in mathematics teacher noticing. *Educational Studies in Mathematics*, *97*(1), 55–69. https://doi.org/10.1007/s10649-017-9775-2

Luna, M. J. (2018). What Does it Mean to Notice my Students' Ideas in Science Today?: An Investigation of Elementary Teachers' Practice of Noticing their Students' Thinking in Science. *Cognition and Instruction*, *36*(4), 297–329. https://doi.org/10.1080/07370008.2018.1496919

Luna, M. J., & Sherin, M. G. (2017a). Using a video club design to promote teacher attention to students' ideas in science. *Teaching and Teacher Education*, *66*, 282–294. https://doi.org/10.1016/j.tate.2017.04.019

Luna, M. J., & Sherin, M. G. (2017b). Using a video club design to promote teacher attention to students' ideas in science. *Teaching and Teacher Education*, *66*, 282–294. https://doi.org/10.1016/j.tate.2017.04.019

Ma, T., Brown, I. A., Kulm, G., Davis, T. J., Lewis, C. W., & Allen, G. D. (2016). Constructing and Role-Playing Student Avatars in a Simulation of Teaching Algebra for Diverse Learners. *Urban Education*, *51*(5), 534–555. https://doi.org/10.1177/0042085914542658

Mahon, J., Bryant, B., Brown, B., & Kim, M. (2010). Using Second Life to enhance classroom management practice in teacher education. *Educational Media International*, *47*(2), 121–134. https://doi.org/10.1080/09523987.2010.492677

Marquart, C. L., Hinojosa, C., Swiecki, Z., Eagan, B., & Shaffer, D. W. (2018). *ENA Web Tool (version 1.7.0)*. https://app.epistemicnetwork.org/login.html

Martin, J. R., & Veel, R. (Eds.). (1998). *Reading science: Critical and functional perspectives on discourses of science*. Routledge.

Martini, M., Perez-Marcos, D., & Sanchez-Vives, M. V. (2014). Modulation of pain threshold by virtual body ownership: Virtual body ownership and pain threshold. *European Journal of Pain*, *18*(7), 1040–1048. https://doi.org/10.1002/j.1532-2149.2014.00451.x

Maskiewicz, A. C., & Winters, V. A. (2012). Understanding the co-construction of inquiry practices: A case study of a responsive teaching environment. *Journal of Research in Science Teaching*, *49*(4), 429–464. https://doi.org/10.1002/tea.21007

Mason, J. (2002). *Researching your own practice: The discipline of noticing / John Mason*. London : RoutledgeFalmer, 2002.

Mason, J. (2011). *Noticing: Roots and branches* (M. G. Sherin, V. R. Jacobs, & R. A. Philipp, Eds.; pp. 35–50). Routledge. http://www.routledge.com/books/details/9780415878623/

Mason, J. (2016). Perception, interpretation and decision making: Understanding gaps between competence and performance—a commentary. *ZDM*, *48*(1), 219–226. https://doi.org/10.1007/s11858-016-0764-1

Mason, J., & Davis, B. (2013). The Importance of Teachers' Mathematical Awareness for In-the-Moment Pedagogy. *Canadian Journal of Science, Mathematics and Technology Education*, *13*(2), 182–197. https://doi.org/10.1080/14926156.2013.784830

Mason, J., & Metz, M. (2017). Chapter 15 - Digging Beneath Dual Systems Theory and the Bicameral Brain: Abductions About the Human Psyche From Experience in Mathematical Problem Solving. In U. Xolocotzin Eligio (Ed.), *Understanding Emotions in Mathematical Thinking and Learning* (pp. 379–407). Academic Press. https://doi.org/10.1016/B978-0-12-802218-4.00015-7

Mason, J., & Spence, M. (1999). Beyond Mere Knowledge of Mathematics: The Importance of Knowing-To Act in the Moment. *Educational Studies in Mathematics*, *38*(1/3), 135–161.

Matusov, E. (2009). *Journey into dialogic pedagogy*. Nova Science Publishers.

McIntyre, L. (2019). *The Scientific Attitude: Defending Science from Denial, Fraud, and Pseudoscience*. MIT Press.

McKenney, S. E., & Reeves, T. C. (2012). *Conducting educational design research*. Routledge.

McKeown, M. G., & Beck, I. L. (2004). Transforming Knowledge into Professional Development Resources: Six Teachers Implement a Model of Teaching for Understanding Text. *Elementary School Journal*, *104*(5), 391.

Mercer, N. (2019). *Language and the Joint Creation of Knowledge: The Selected Works of Neil Mercer* (1st ed.). Routledge. https://doi.org/10.4324/9780429400759

Mercer, N., & Dawes, L. (2008). The Value of Exploratory Talk. In N. Mercer & S. Hodgkinson, *Exploring Talk in School: Inspired by the Work of Douglas Barnes* (pp. 55–72). SAGE Publications Ltd. https://doi.org/10.4135/9781446279526.n4

Mercer, N., Dawes, L., & Staarman, J. K. (2009). Dialogic teaching in the primary science classroom. *Language and Education*, *23*(4), 353–369. https://doi.org/10.1080/09500780902954273

Mercer, N., Dawes, L., Wegerif, R., & Sams, C. (2004). Reasoning as a scientist: Ways of helping children to use language to learn science. *British Educational Research Journal*, *30*(3), 359–377. https://doi.org/10.1080/01411920410001689689

Mercer, N., & Wegerif, R. (2004). Is “exploratory talk” productive talk? In H. Daniels & A. Edwards (Eds.), *The RoutledgeFalmer Reader in Psychology of Education* (pp. 67–86). RoutledgeFalmer.

Meritt, J., Gibson, D., Christensen, R., & Knezek, G. (2013). *Interactive technologies for teacher training: Comparing performance and assessment in second life and simSchool*. 5.

Meschede, N., Fiebranz, A., Möller, K., & Steffensky, M. (2017). Teachers’ professional vision, pedagogical content knowledge and beliefs: On its relation and differences between pre-service and in-service teachers. *Teaching and Teacher Education*, *66*, 158–170. https://doi.org/10.1016/j.tate.2017.04.010

Michaels, & O'Connor. (2012). *Talk science primer*. TERC. https://inquiryproject.terc.edu/shared/pd/TalkScience_Primer.pdf

Michaels, S., & O'Connor, C. (2015). Conceptualizing Talk Moves as Tools: Professional Development Approaches for Academically Productive Discussions. In L. B. Resnick, C. S. C. Asterhan, & S. N. Clarke (Eds.), *Socializing Intelligence Through Academic Talk and Dialogue* (pp. 347–361). American Educational Research Association. https://doi.org/10.3102/978-0-935302-43-1_27

Michaels, S., O'Connor, C., & Resnick, L. B. (2008). Deliberative Discourse Idealized and Realized: Accountable Talk in the Classroom and in Civic Life. *Studies in Philosophy and Education*, *27*(4), 283–297. https://doi.org/10.1007/s11217-007-9071-1

Milgram, P., & Colquhoun, H. (2001). *A Taxonomy of Real and Virtual World Display Integration*. https://doi.org/10.1007/978-3-642-87512-0_1

Ministry of Federal Education and Professional Training. (2017). *National Education Policy 2017*. https://planipolis.iiep.unesco.org/sites/planipolis/files/ressources/pakistan_national_education_policy_2017-2025.pdf

Mortimer, & Scott. (2003). *Meaning Making in Secondary Science Classroom*. Open University Press.

Msimanga, A., & Lelliott, A. (2012). Making Sense of Science: Argumentation for Meaning-Making in a Teacher-Led Whole Class Discussion. *African Journal of Research in Mathematics, Science and Technology Education*, *16*(2), 192–206. Education Collection. https://doi.org/10.1080/10288457.2012.10740739

Mueller, A. (1997). Discourse of Scientific Inquiry in the Elementary Classroom. *Journal of Elementary Science Education*, *9*(1), 15–33.

Muir, T., Allen, J. M., Rayner, C. S., & Cleland, B. (2013). Preparing pre-service teachers for classroom practice in a virtual world: A pilot study using Second Life. *Journal of Interactive Media in Education*, *2013*(1), 3. https://doi.org/10.5334/2013-03

Müller, N. G., Bartelt, O. A., Donner, T. H., Villringer, A., & Brandt, S. A. (2003). A Physiological Correlate of the "Zoom Lens" of Visual Attention. *Journal of Neuroscience*, *23*(9), 3561–3565. https://doi.org/10.1523/JNEUROSCI.23-09-03561.2003

Neuendorf, K. A. (2017). *The Content Analysis Guidebook*. SAGE Publications, Inc. https://doi.org/10.4135/9781071802878

Nguyen, Q., & Raju, D. (2014). *Private School Participation in Pakistan*. 69.

Nonaka, I., Toyama, R., & Konno, N. (2000). SECI, Ba and Leadership: A Unified Model of Dynamic Knowledge Creation. *Long Range Planning*, *33*(1), 5–34. https://doi.org/10.1016/S0024-6301(99)00115-6

Nystrand, M. (1997). *Opening dialogue: Understanding the dynamics of language and learning in the English classroom*. Teachers College Press.

O'Connor, C., & Michaels, S. (2007). When Is Dialogue 'Dialogic'? *Human Development*, *50*(5), 275–285. https://doi.org/10.1159/000106415

O'Connor, C., & Michaels, S. (2019). Supporting teachers in taking up productive talk moves: The long road to professional learning at scale. *International Journal of Educational Research*, *97*, 166–175. https://doi.org/10.1016/j.ijer.2017.11.003

O'Connor, M. C., & Michaels, S. (1996). Shifting participant frameworks: Orchestrating thinking practices in group discussion. In D. Hicks (Ed.), *Discourse, Learning, and Schooling* (1st ed., pp. 63–103). Cambridge University Press. https://doi.org/10.1017/CBO9780511720390.003

Odden, T. O. B., & Russ, R. S. (2019). Defining sensemaking: Bringing clarity to a fragmented theoretical construct. *Science Education*, *103*(1), 187–205. https://doi.org/10.1002/sce.21452

Osborne, J. (2015). The Challenge to Scale. In L. Resnick, C. Asterhan, & S. Clarke (Eds.), *Socializing Intelligence Through Academic Talk and Dialogue* (pp. 403–414). American

Educational Research Association.
http://ebookcentral.proquest.com/lib/cam/detail.action?docID=4866316

Osborne, J., & Chin, C. (2010). The role of discourse in learning science. In K. Littleton & C. Howe (Eds.), *Educational dialogues: Understanding and promoting productive interaction*. Routledge.

Osborne, J., Simon, S., Christodoulou, A., Howell-Richardson, C., & Richardson, K. (2013). Learning to argue: A study of four schools and their attempt to develop the use of argumentation as a common instructional practice and its impact on students. *Journal of Research in Science Teaching*, *50*, 315–347. https://doi.org/10.1002/tea.21073

Park, J., Michaels, S., Affolter, R., & O'Connor, C. (2017, December 19). *Traditions, Research, and Practice Supporting Academically Productive Classroom Discourse*. Oxford Research Encyclopedia of Education. https://doi.org/10.1093/acrefore/9780190264093.013.21

Pas, E. T., Johnson, S. R., Larson, K. E., Brandenburg, L., Church, R., & Bradshaw, C. P. (2016). Reducing Behavior Problems Among Students with Autism Spectrum Disorder: Coaching Teachers in a Mixed-Reality Setting. *Journal of Autism and Developmental Disorders*, *46*(12), 3640-. Gale Academic OneFile.

Pea, R. D. (2004). The Social and Technological Dimensions of Scaffolding and Related Theoretical Concepts for Learning, Education, and Human Activity. *The Journal of the Learning Sciences*, *13*(3,), 423–451.

Pehmer, A.-K., Gröschner, A., & Seidel, T. (2015). Fostering and scaffolding student engagement in productive classroom discourse: Teachers' practice changes and reflections in light of teacher professional development. *Learning, Culture and Social Interaction*, *7*, 12–27. https://doi.org/10.1016/j.lcsi.2015.05.001

Phillipson, N. (2020). A Teacher's Guide to Dialogic Pedagogy Part 1: The What and the Why. *21st Century Learners*. http://21stcenturylearners.org.uk/?p=1337

Phillipson, N., & Wegerif, R. (2016). *Dialogic Education: Mastering core concepts through thinking together* (1st ed.). Routledge. https://doi.org/10.4324/9781315621869

Pierson, J. L. (2008). *The relationship between patterns of classroom discourse and mathematics learning* [Ph.D., The University of Texas at Austin]. https://www.proquest.com/docview/304482383/abstract/302B34C6986D48A8PQ/1

Plato. (2014). *The Republic.* CreateSpace Independent Publishing Platform.

Reach Every Reader. (2020, July 22). Three-part mini-series on the use of Mursion simulation technology in Reach Every Reader for teacher development. *Reach Every Reader.* https://reacheveryreader.gse.harvard.edu/developing-teachers-as-critical-thinkers-and-learners/

Reeves, T. (2006). Design research from a technology perspective. In *Educational design research* (pp. 64–78). Routledge.

Renshaw, P. D. (2004). Dialogic Learning Teaching and Instruction. In J. van der Linden & P. Renshaw (Eds.), *Dialogic Learning: Shifting Perspectives to Learning, Instruction, and Teaching* (pp. 1–15). Springer Netherlands. https://doi.org/10.1007/1-4020-1931-9_1

Resnick, L., Asterhan, C., & Clarke, S. (2015). *Socializing Intelligence Through Academic Talk and Dialogue.* American Educational Research Association. http://ebookcentral.proquest.com/lib/cam/detail.action?docID=4866316

Resnick, L., Asterhan, C., & Clarke, S. (2018). *Accountable Talk: Instructional dialogue that builds the mind.*

Reznitskaya, A., Glina, M., Carolan, B., Michaud, O., Rogers, J., & Sequeira, L. (2012). Examining transfer effects from dialogic discussions to new tasks and contexts. *Contemporary Educational Psychology*, *37*(4), 288–306. https://doi.org/10.1016/j.cedpsych.2012.02.003

Reznitskaya, A., & Wilkinson, I. (2015). Professional Development in Dialogic Teaching: Helping Teachers Promote Argument Literacy in Their Classrooms. In *The SAGE*

Handbook of Learning (pp. 219–231). SAGE Publications Ltd. https://doi.org/10.4135/9781473915213

Richards, J., Elby, A., Luna, M. J., Robertson, A. D., Levin, D. M., & Nyeggen, C. G. (2020). Reframing the Responsiveness Challenge: A Framing-Anchored Explanatory Framework to Account for Irregularity in Novice Teachers' Attention and Responsiveness to Student Thinking. *Cognition and Instruction*, *38*(2), 116–152. https://doi.org/10.1080/07370008.2020.1729156

Richter, S. (2019). A system dynamics study of Pakistan's education system: Consequences for governance. *The Electronic Journal of Information Systems in Developing Countries*, *85*(1), e12065. https://doi.org/10.1002/isd2.12065

Rimel, A. (2020). *Mursion Lab gives students opportunity to train in virtual classroom – College of Education*. https://wou.edu/education/highlights/mursion-lab-gives-students-opportunity-to-train-in-virtual-classroom/

Robertson, A. D., Richards, J., Elby, A., & Walkoe, J. (2016). Documenting Variability within Teacher Attention and Responsiveness to the Substance of Student Thinking. In *Responsive Teaching in Science and Mathematics* (pp. 227–249). Routledge.

Rolim, V., Ferreira, R., Lins, R. D., & Găsević, D. (2019). A network-based analytic approach to uncovering the relationship between social and cognitive presences in communities of inquiry. *The Internet and Higher Education*, *42*, 53–65. https://doi.org/10.1016/j.iheduc.2019.05.001

Roth, W.-M. (2002). *Being and becoming in the classroom*. Ablex Pub.

Ruis, A. R., Rosser, A. A., Nathwani, J. N., Beems, M. V., Jung, S. A., & Pugh, C. M. (2019). Multiple Uses for Procedural Simulators in Continuing Medical Education Contexts. In B. Eagan, M. Misfeldt, & A. Siebert-Evenstone (Eds.), *Advances in Quantitative Ethnography* (Vol. 1112, pp. 211–222). Springer International Publishing. https://doi.org/10.1007/978-3-030-33232-7_18

Russ, R. S., & Luna, M. J. (2013). Inferring teacher epistemological framing from local patterns in teacher noticing. *Journal of Research in Science Teaching*, *50*(3), 284–314. https://doi.org/10.1002/tea.21063

Russ, R. S., Scherr, R. E., Hammer, D., & Mikeska, J. (2008). Recognizing mechanistic reasoning in student scientific inquiry: A framework for discourse analysis developed from philosophy of science. *Science Education*, *92*(3), 499–525. https://doi.org/10.1002/sce.20264

Ruthven, K., Mercer, N., Taber, K. S., Guardia, P., Hofmann, R., Ilie, S., Luthman, S., & Riga, F. (2017). A research-informed dialogic-teaching approach to early secondary school mathematics and science: The pedagogical design and field trial of the epiSTEMe intervention. *Research Papers in Education*, *32*(1), 18–40. https://doi.org/10.1080/02671522.2015.1129642

Ryu, S., & Sandoval, W. A. (2012). Improvements to elementary children's epistemic understanding from sustained argumentation. *Science Education*, *96*(3), 488–526. https://doi.org/10.1002/sce.21006

Sampson, V., & Clark, D. (2007). Incorporating scientific argumentation into inquiry-based activities with online personally-seeded discussions. *The Science Scope*, *30*, 43–47.

Sandoval, W. (2014). Conjecture Mapping: An Approach to Systematic Educational Design Research. *Journal of the Learning Sciences*, *23*(1), 18–36. https://doi.org/10.1080/10508406.2013.778204

Santagata, R., König, J., Scheiner, T., Nguyen, H., Adleff, A.-K., Yang, X., & Kaiser, G. (2021). Mathematics teacher learning to notice: A systematic review of studies of video-based programs. *ZDM – Mathematics Education*, *53*(1), 119–134. https://doi.org/10.1007/s11858-020-01216-z

Satubaldina, A. (2018, May 5). *QazGeo to launch expeditions to Aral Sea, sacred Kazakh places*. The Astana Times. https://astanatimes.com/2018/05/qazgeo-to-launch-expeditions-to-aral-sea-sacred-kazakh-places/

Sawyer, R. K. (2004). Creative Teaching: Collaborative Discussion as Disciplined Improvisation. *Educational Researcher*, *33*(2), 12–20. https://doi.org/10.3102/0013189X033002012

Scardamalia, M., & Bereiter, C. (2014). Knowledge Building and Knowledge Creation: Theory, Pedagogy, and Technology. In R. K. Sawyer (Ed.), *The Cambridge Handbook of the Learning Sciences* (2nd ed., pp. 397–417). Cambridge University Press. https://doi.org/10.1017/CBO9781139519526.025

Schad, D. J., & Engbert, R. (2012). The zoom lens of attention: Simulating shuffled versus normal text reading using the SWIFT model. *Visual Cognition*, *20*(4–5), 391–421. https://doi.org/10.1080/13506285.2012.670143

Scheiner, T. (2021). Towards a more comprehensive model of teacher noticing. *ZDM – Mathematics Education*, *53*(1), 85–94. https://doi.org/10.1007/s11858-020-01202-5

Schoenfeld, A. H. (2010). *How We Think: A Theory of Goal-Oriented Decision Making and its Educational Applications*. Routledge. https://doi.org/10.4324/9780203843000

Schreier, M. (2020). Content Analysis, Qualitative. In *SAGE Research Methods Foundations*. SAGE Publications Ltd. https://doi.org/10.4135/9781526421036753373

Schwartz, D. L., Bransford, J. D., & Sears, D. (2005). Efficiency and innovation in transfer. *Transfer of Learning from a Modern Multidisciplinary Perspective*, *3*, 1–51.

Schwarz, C. V., Braaten, M., Haverly, C., & de los Santos, E. X. (2021). Using Sense-Making Moments to Understand How Elementary Teachers' Interactions Expand, Maintain, or Shut Down Sense-making in Science. *Cognition and Instruction*, *39*(2), 113–148. https://doi.org/10.1080/07370008.2020.1763349

Scott, P., & Ametller, J. (2007). Teaching science in a meaningful way: Striking a balance between 'opening up' and 'closing down' classroom talk. *School Science Review*, 9.

Sedova, K. (2017). A case study of a transition to dialogic teaching as a process of gradual change. *Teaching and Teacher Education*, *67*, 278–290. https://doi.org/10.1016/j.tate.2017.06.018

Sedova, K., & Navratilova, J. (2020). Silent students and the patterns of their participation in classroom talk. *Journal of the Learning Sciences*, *29*(4–5), 681–716. https://doi.org/10.1080/10508406.2020.1794878

Sedova, K., Salamounova, Z., & Svaricek, R. (2014). Troubles with dialogic teaching. *Learning, Culture and Social Interaction*, *3*(4), 274–285. https://doi.org/10.1016/j.lcsi.2014.04.001

Sfard, A. (2008). *Thinking as Communicating: Human Development, the Growth of Discourses, and Mathematizing*. Cambridge University Press. https://doi.org/10.1017/CBO9780511499944

Shaffer, D. W. (2006). Epistemic frames for epistemic games. *Computers & Education*, *46*(3), 223–234. https://doi.org/10.1016/j.compedu.2005.11.003

Shaffer, D. W. (2017). *Quantitative Ethnography*. Cathcart Press.

Shaffer, D. W., Collier, W., & Ruis, A. R. (2016). A Tutorial on Epistemic Network Analysis: Analyzing the Structure of Connections in Cognitive, Social, and Interaction Data. *Journal of Learning Analytics*, *3*(3), Article 3. https://doi.org/10.18608/jla.2016.33.3

Sherin, M. (2007). The Development of Teachers' Professional Vision in Video Clubs. In *Video Research in the Learning Sciences*. Routledge.

Sherin, M. (2011). *Mathematics Teacher Noticing: Seeing Through Teachers' Eyes* (1st ed.). Routledge. https://doi.org/10.4324/9780203832714

Sherin, M. G., Russ, R. S., & Colestock, A. A. (2011). Accessing Mathematics Teachers' In-the-Moment Noticing. In M. Sherin, V. Jacobs, & R. Philipp (Eds.), *Mathematics Teacher Noticing* (0 ed., pp. 79–94). Routledge. https://doi.org/10.4324/9780203832714

Shulman, L. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review*, *57*(1), 1–23. https://doi.org/10.17763/haer.57.1.j463w79r56455411

Siebert-Evenstone, A. L., Irgens, G. A., Collier, W., Swiecki, Z., Ruis, A. R., & Shaffer, D. W. (2017). In Search of Conversational Grain Size: Modeling Semantic Structure using Moving Stanza Windows. *Journal of Learning Analytics*, *4*(3), Article 3. https://doi.org/10.18608/jla.2017.43.7

Simons, D. J., & Chabris, C. F. (1999). Gorillas in Our Midst: Sustained Inattentional Blindness for Dynamic Events. *Perception*, *28*(9), 1059–1074. https://doi.org/10.1068/p281059

SimSchool. (n.d.). Retrieved August 22, 2020, from https://www.simschool.org/home/simschool/

simSchool Educator Training (Director). (2020, April 26). *simSchool Fast Facts: Teaching in simSchool*. https://www.youtube.com/watch?v=rLPhxIyq-hg

Stigler, J. W., & Hiebert, J. (2016). Lesson study, improvement, and the importing of cultural routines. *ZDM*, *48*(4), 581–587. https://doi.org/10.1007/s11858-016-0787-7

Tabak, I. (2004). Reconstructing Context: Negotiating the Tension Between Exogenous and Endogenous Educational Design. *Educational Psychologist*, *39*(4), 225–233. https://doi.org/10.1207/s15326985ep3904_4

Tabak, I., & Baumgartner, E. (2004). The Teacher as Partner: Exploring Participant Structures, Symmetry, and Identity Work in Scaffolding. *Cognition and Instruction*, *22*(4), 393–429. https://doi.org/10.1207/s1532690Xci2204_2

Taber, K. S. (2019). Experimental research into teaching innovations: Responding to methodological and ethical challenges. *Studies in Science Education*, *55*(1), 69–119. https://doi.org/10.1080/03057267.2019.1658058

Tan, A.-L., & Tang, K. S. (2019). The role of dialogue in science epistemic practices. In *The Routledge International Handbook of Research on Dialogic Education*. Routledge.

Tannen, D. (1993). *Framing in Discourse*. Oxford University Press.

Tekkumru Kisa, M., & Stein, M. K. (2015). Learning to See Teaching in New Ways: A Foundation for Maintaining Cognitive Demand. *American Educational Research Journal*, *52*(1), 105–136. https://doi.org/10.3102/0002831214549452

The Argumentation Toolkit. (n.d.). The Argumentation Toolkit. Retrieved August 23, 2020, from http://www.argumentationtoolkit.org/

Thompson, J., Hagenah, S., Kang, H., Stroupe, D., Braaten, M., Colley, C., & Windschitl, M. (2016). Rigor and Responsiveness in Classroom Activity. *Teachers College Record*, 58.

Thomspon, J., Hagenah, S., Kang, H., Stroupe, D., Braaten, M., Colley, C., & Windschitl, M. (2016). Rigor and Responsiveness in Classroom Activity. *Teachers College Record*, *118*(5).

UNICEF. (2020, February 25). *Education in Pakistan*. WENR. https://wenr.wes.org/2020/02/education-in-pakistan

van den Akker, J. (1999). Principles and Methods of Development Research. In J. van den Akker, R. M. Branch, K. Gustafson, N. Nieveen, & T. Plomp (Eds.), *Design Approaches and Tools in Education and Training* (pp. 1–14). Springer Netherlands. https://doi.org/10.1007/978-94-011-4255-7_1

Van den Akker, J., Gravemeijer, K., McKenney, S., & Nieveen, N. (Eds.). (2006). *Educational Design Research* (1st ed.). Routledge. https://doi.org/10.4324/9780203088364

van der Land, S. F., Schouten, A. P., Feldberg, F., Huysman, M., & van den Hooff, B. (2015). Does Avatar Appearance Matter? How Team Visual Similarity and Member–Avatar Similarity Influence Virtual Team Performance. *Human Communication Research*, *41*(1), 128–153. https://doi.org/10.1111/hcre.12044

van Es, E. A., Hand, V., & Mercado, J. (2017). Making Visible the Relationship Between Teachers' Noticing for Equity and Equitable Teaching Practice. In E. O. Schack, M. H. Fisher, & J. A. Wilhelm (Eds.), *Teacher Noticing: Bridging and Broadening Perspectives, Contexts, and Frameworks* (pp. 251–270). Springer International Publishing. https://doi.org/10.1007/978-3-319-46753-5_15 van Es, E., & Sherin, M. (2002). Learning to Notice: Scaffolding New Teachers' Interpretations of Classroom Interactions. *Journal of Technology and Teacher Education*, *10*.

Vrikki, M., Wheatley, L., Howe, C., Hennessy, S., & Mercer, N. (2019). Dialogic practices in primary school classrooms. *Language and Education*, *33*(1), 85–100. https://doi.org/10.1080/09500782.2018.1509988

Vygotsky, L. S. (1978). *Mind in Society: Development of Higher Psychological Processes*. Harvard University Press.

Walkoe, J., & Luna, M. J. (2020). What We are Missing in Studies of Teacher Learning: A Call for Microgenetic, Interactional Analyses to Examine Teacher Learning Processes. *Journal of the Learning Sciences*, *29*(2), 285–307. https://doi.org/10.1080/10508406.2019.1681998

Wallace, P., & Maryott, J. (2009). The Impact of Avatar Self-Representation on Collaboration in Virtual Worlds. *Innovate: Journal of Online Education*, *5*(5). https://www.learntechlib.org/p/104219/

Walters, S. M., Hirsch, S. E., McKown, G., Carlson, A., & Allen, A. A. (2021). Mixed-Reality Simulation with Preservice Teacher Candidates: A Conceptual Replication. *Teacher Education and Special Education*, *44*(4), 340–355.

Warren, B., Ballenger, C., Ogonowski, M., Rosebery, A. S., & Hudicourt-Barnes, J. (2001). Rethinking diversity in learning science: The logic of everyday sense-making. *Journal of Research in Science Teaching*, *38*(5), 529–552. https://doi.org/10.1002/tea.1017

Wegerif. (2011). Towards a dialogic theory of how children learn to think. *Thinking Skills and Creativity*, *6*, 179–190.

Wegerif, R. (1996). Collaborative Learning and Directive Software. *Journal of Computer Assisted Learning*, *12*(1), 22–32.

Wegerif, R. (2004). The role of educational software as a support for teaching and learning conversations. *Computers & Education*, *43*(1), 179–191. https://doi.org/10.1016/j.compedu.2003.12.012

Wegerif, R. (2007a). *Dialogic Education and Technology: Expanding the Space of Learning*. Springer US. https://doi.org/10.1007/978-0-387-71142-3

Wegerif, R. (Ed.). (2007b). Dialogic: Opening a Space. In *Dialogic Education and Technology: Expanding the Space of Learning* (pp. 13–29). Springer US. https://doi.org/10.1007/978-0-387-71142-3_2

Wegerif, R. (2008). Dialogic or dialectic? The significance of ontological assumptions in research on educational dialogue. *British Educational Research Journal*, *34*(3), 347–361. https://doi.org/10.1080/01411920701532228

Wegerif, R. (2010). *Mind expanding teaching for thinking and creativity in primary education*. McGraw-Hill : Open University Press. http://site.ebrary.com/id/10441948

Wegerif, R. (2011a). From Dialectic to Dialogic. In T. Koschmann (Ed.), *Theories of Learning and Studies of Instructional Practice* (pp. 201–221). Springer. https://doi.org/10.1007/978-1-4419-7582-9_12

Wegerif, R. (2011b). Towards a dialogic theory of how children learn to think. *Thinking Skills and Creativity*, *6*(3), 179–190. https://doi.org/10.1016/j.tsc.2011.08.002

Wegerif, R. (2013). *Dialogic: Education for the Internet Age*. Routledge.

Wegerif, R. (2016). Dialogue with a tree? *Rupert Wegerif*. http://www.rupertwegerif.name/1/post/2016/08/dialogue-with-a-tree.html

Wegerif, R. (2017). Dialogic Space, and why we need it. *Rupert Wegerif*. http://www.rupertwegerif.name/1/post/2017/09/dialogic-space-why-we-need-it.html

Wegerif, R. (2020). Introduction to the theory of dialogic education. In *The Routledge International Handbook of Research on Dialogic Education* (pp. 11–13).

Wegerif, R. B. (2020). Researching Online Dialogues: Introducing the 'Chiasm' Methodology. In R. Kershner, S. Hennessy, R. Wegerif, & A. Ahmed (Eds.), *Research Methods for Educational Dialogue*. Bloomsbury Academic. https://doi.org/10.5040/9781350060111

Wegerif, R., Kershner, R., Hennessy, S., & Ahmed, A. (2020). Foundations for Research on Educational Dialogue. In *Research Methods for Educational Dialogue*. Bloombury Academic.

Wegerif, R., Littleton, K., & Jones, A. (2003). Stand-alone computers supporting learning dialogues in primary classrooms. *International Journal of Educational Research*, *39*(8), 851–860. https://doi.org/10.1016/j.ijer.2004.11.007

Wegerif, R., & Major, L. (2019). Buber, educational technology, and the expansion of dialogic space. *AI & SOCIETY*, *34*(1), 109–119. https://doi.org/10.1007/s00146-018-0828-6

Wegerif, R., Postlethwaite, K., Skinner, N., Mansour, N., Morgan, A., & Hetherington, L. (2013). Dialogic Science Education for Diversity. In N. Mansour & R. Wegerif (Eds.), *Science Education for Diversity: Theory and Practice* (pp. 3–22). Springer Netherlands. https://doi.org/10.1007/978-94-007-4563-6_1

Wells, G. (1999). *Dialogic Inquiry: Towards a Socio-cultural Practice and Theory of Education* (1st ed.). Cambridge University Press. https://doi.org/10.1017/CBO9780511605895

Wells, G., & Arauz, R. M. (2006). Dialogue in the Classroom. *Journal of the Learning Sciences*, *15*(3), 379–428. https://doi.org/10.1207/s15327809jls1503_3

Wilkinson, I. A. G., Reznitskaya, A., Bourdage, K., Oyler, J., Glina, M., Drewry, R., Kim, M.-Y., & Nelson, K. (2017). Toward a more dialogic pedagogy: Changing teachers' beliefs and practices through professional development in language arts classrooms. *Language and Education*, *31*(1), 65–82. https://doi.org/10.1080/09500782.2016.1230129

Windschitl, M., Thompson, J. J., & Braaten, M. L. (2018). *Ambitious science teaching*. Harvard Education Press.

Wiske, M. S. (Ed.). (1998). *Teaching for understanding: Linking research with practice* (1st ed). Jossey-Bass Publishers.

World Bank. (2019). *Pakistan: Learning Poverty Brief* (EduAnalytics). https://thedocs.worldbank.org/en/doc/214101571223451727-0090022019/original/SASSACPKPAKLPBRIEF.pdf

Yang, X., Kaiser, G., König, J., & Blömeke, S. (2020). Relationship between pre-service mathematics teachers' knowledge, beliefs and instructional practices in China. *ZDM*, *52*(2), 281–294. https://doi.org/10.1007/s11858-020-01145-x

Zubairi, A., Halim, W., Kaye, T., & Wilson, S. (2021). *Country-Level Research Review: EdTech in Pakistan*. EdTech Hub.