Insights and lessons from teachers' initial professional learning and
collaborative practices in questioning for higher-order scientific discourse
in primary science classrooms

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Abstract

The purpose of this study is to understand the processes of teacher learning and collaboration when teachers are initiated into a professional development programme focusing on questioning to promote higher-order scientific discourse. The study will inform the design of school-based professional development on teacher questioning. Two Primary Four and two Primary Five science teachers from a Singapore primary school participated in a school-based professional development, comprising learning experiences designed for individual teachers and for teachers working together. The teachers were first introduced to Chin's (2007) questioning framework of four questioning approaches (Socratic questioning, verbal jigsaw, semantic tapestry, framing) at workshop sessions. They also conducted a total of sixteen lessons covering the topics of Heat, Light, Plant Reproduction and Plant Processes and participated in post lesson reflections.

Data were collected by audio-recording workshop discussions, video-recording enacted lessons and audio-recording post lesson discussions. To analyse teachers' evidence of learning, the interconnected model of professional growth by Clarke and Hollingsworth (2002) was used. The model also facilitated the presentation and comparison of teachers' change sequences and growth networks in the personal domain of knowledge and belief, domain of practice and domain of consequence of salient outcomes arising from external domain of stimuli. All teachers changed but in different ways.

Overall, the study has contributed empirical evidence on how teachers enacted and reflected on questioning in an authentic school setting, providing insights into the complexity of teacher learning and practices individually and with other teachers across various learning experiences. It has also provided insights into the potential of the model of Clarke and Hollingsworth (2002) as an analytical tool, not just for individual teachers but for teachers learning together. The features of school-based professional development that facilitated learning have informed the design of inquiry professional development. Findings from this study will inform me as a science curriculum specialist in designing curriculum, resources and professional

development to better support questioning to nurture effective inquirers and critical thinkers in the 21st century.

Declaration of Word Count

I hereby declare that, except where explicit attribution is made, the work presented in this thesis is entirely my own. Word count (exclusive of appendices, the list of references and bibliographies but including footnotes, endnotes, glossary, maps, diagrams and tables):

45316 words

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Reflective Statement

This reflective statement is a summary and synthesis of my EdD learning experiences including the four taught modules, the Institution Focused Study (IFS) and the thesis. Writing this statement allows me to make links between the different learning experiences and reflect on how the EdD programme has contributed to my professional knowledge and development as a science curriculum specialist in the Curriculum Planning and Development Division at the Ministry of Education of Singapore.

Brief description of and reflection on the four taught modules, institution focused study (IFS) and thesis

The taught modules contributed to my development of competence and understanding of professional enquiry and reflection, which has formed the basis for my final thesis on understanding how teachers learn and collaborate in questioning to promote scientific discourse in local primary science classrooms.

In the first module on "Foundations of Professionalism in Education", I was introduced to the definition of a good professional as one who designs using good and careful prescriptive logic, logic which correctly governs the identification of ends and their implications (Simon, 1996). This definition led me to think more deeply about the role of a good science professional, including my role as a science teacher for seven years and a curriculum specialist for ten years. Having implemented the curriculum as a science teacher and now designing the curriculum to support teachers in implementing the curriculum, I believe in the complementary roles of science teachers and curriculum specialists for successful curriculum implementation. Hence, in my module one assignment, I discussed the roles of science teachers and curriculum specialists in relation to how they can support students' learning using the three research based principles of learning

(Bransford, Brown & Cocking, 2000). This led me to the conceptualisation of a model of science curriculum partnership consisting of five stages (Understand-Engage-Collaborate-Reflect-Share). The model allowed me to articulate the roles of science teachers and curriculum specialists to guide the curriculum partnership and professional development of science teachers in Singapore for the current primary science curriculum. While conceptualising this model of curriculum partnership and professional development, the engagement with both local and international literature on science teaching and learning as well as teacher professional development is useful in informing my work, especially in the second and fourth taught modules, the IFS as well as the thesis.

The second "Educational Research" module assignment was a meaningful continuation of the first assignment as I had the opportunity to design research focusing on an important aspect of a science professional - teacher questioning. I experienced the process of conceptualising research using the literature to establish the significance of exploring how teachers used questioning to align curriculum, instruction and assessment to promote scientific discourse in the professional context of my work. Based on the issues explored in the literature as well as the rationale and context of study, I experienced defining and refining my research questions. Besides, I designed my theoretical framework using an existing theory-based model for aligning curriculum, instruction and assessment (Farenga, Joyce & Ness, 2002) and explored possibilities in data collection and analysis. It was also useful to think through the political and ethical issues in the design, conduct, dissemination and use of my research, given my role as a specialist to support schools in syllabus implementation. This exposure to conceptualising a research was useful in finally conceptualising both my IFS and thesis.

In the third "International Education" module assignment, I looked beyond science education and the Singapore context to discuss challenges and tensions that globalisation in its various manifestations - political, economic and cultural (Burbules & Torres, 2000) - poses to education in transitional states, focusing on

Timor-Leste. While there are common challenges and tensions which are more pertinent to transitional states, I recognise that some issues such as teacher quality is of paramount importance to even more developed nations including Singapore. I believe that teacher quality is related to "teacher professionalism" that I discussed in the taught module one. I also think that ensuring teacher quality is not just the responsibility of the states but the responsibility of teachers themselves in continually developing themselves professionally. This reflection on teacher quality and professionalism reaffirmed my belief in teachers' ownership of their own learning and led me to my thesis where I decided finally to focus on studying teachers' learning and collaboration in questioning to promote scientific discourse.

In the fourth module assignment on "Methods of Enquiry", I built on the research conceptualised in my taught module two assignment to try out my own analytical framework. While trying to use the earlier analytical framework proposed in the taught module two assignment to make sense of the data that I collected, I recognised the need to refine the framework to better represent, analyse and code the teacher-student discourse. The earlier framework focused on the classification of teacher's questions and students' responses specifically into curriculum, instruction and assessment. This was problematic as the teacher's questions and students' responses may not belong to any of the three distinct categories. With this experience in analysing and reflecting on the analytical framework, I was better able to analyse my thesis data, comprising not only scientific discourse in classroom but evidence of learning in teachers' reflections of scientific discourse across workshop and post lesson discussion platforms.

In my IFS, I built on the taught modules two and four to empirically study how and when teachers used questions to promote higher-order scientific discourse. I learned to analyse teacher questioning approaches in scientific discourse for Chin's (2007) four questioning approaches (Socratic questioning, verbal jigsaw, semantic tapestry and framing) which were described initially in the secondary context in Singapore. What was also valuable experience was

observing, analysing and presenting how these four questioning approaches were used with six pedagogies (whole class discussion, investigation, game, role play, concept mapping and information technology) to promote higher cognitive level of student responses. These IFS findings have contributed to literature as little has been reported on how the use of Chin's (2007) questioning approaches with specific pedagogies associated with high cognitive level of student responses. Overall, the study established methods in analysing teacher questioning and student thinking in scientific discourse which were further explored in the thesis.

In the thesis, I continue to empirically study teacher questioning but focusing more on teachers' process of learning in using Chin's (2007) questioning approaches to promote higher order scientific discourse. In view of the different rationale of study compared to the IFS, I designed my own theoretical framework for the thesis by revisiting the principles of learning (Bransford, Brown & Cocking, 2000) which I used in module one, this time to design the framework of learning and collaboration in teacher questioning. What is common between the IFS and thesis is my involvement in both collecting and interpreting data, hence the need to be cautious of researcher bias (Creswell, 2009). Besides using different evidence of learning from workshop journals, lesson observations and post lesson discussions, I also minimised the threat to interpretive validity by supporting my interpretations with evidence of learning. I also used low-level descriptors in reporting, following closely to teachers' reflections. Overall, the thesis has made further contribution in teacher learning as Darling-Hammond and Bransford (2005) highlighted that there is still a lack of research especially on how teacher learning affects teaching practices / student outcomes as well as how teachers learn successful practices. Besides, the thesis findings have also contributed to empirical literature on science inquiry professional development which is found to be lacking by Capps, Crawford and Constas (2012).

Overall, I feel that the four modules have helped me to reflect on the macro issues of professionalism and education and also explore specific issues in roles and practices of science teachers. Having engaged in a variety of literature

and having a firsthand experience in designing a research, I am better equipped with the research skills and academic writing skills to progress towards the IFS and thesis stages.

Relationship between the work in the EdD programme and my professional practice and development

The taught modules, IFS and thesis have led my thinking, analysis and reflection on the roles and practices of science teachers as well as my own role and practices as a curriculum specialist to support them. Innes-Brown (2001) highlighted that education should be reformed "innovatively" but not just "renovatively". My past work practices could be viewed as "renovative" as I had predetermined plans in disseminating resources and training. I would like to shift to more "innovative" practices so that I can respond flexibly to teachers' needs and enable teachers to develop in a community of practice with other teachers.

What I have explored in my IFS and thesis represents a shift to more "innovative" practice. In my IFS, I designed the study to understand teachers' questioning practices and how these questioning practices were used with other pedagogies such as whole class discussion, investigation, game, role play, concept mapping and information technology. Understanding how different combinations of questioning approaches and pedagogies have supported students' learning and thinking has provided useful insights in my design of teaching and learning resources. Since the completion of my IFS, I have started partnering teachers in co-developing and reviewing resources. This has not only enabled the incorporation of teacher-initiated and tested resources but also encouraged teachers' greater ownership in science teaching and learning.

In my thesis, I tried to further understand teachers' process of learning and collaboration in questioning to promote higher-order scientific discourse. By analysing teachers' evidence of learning through their enactment and reflections of Chin's (2007) questioning approaches, I was able to identify how teachers

change and grow across the various planned learning experiences at the workshop and post lesson discussions using the interconnected growth model of Clarke and Hollingsworth (2002). Besides, I also engaged teachers in reflecting on learning experiences which are useful to them. This helped me to identify features of school-based professional development which are useful in the social settings of teachers' own schools. As I explore more "innovative" practices in professional development, I would need to reflect on whether I have achieved the balance of providing sufficient support for teachers with different needs and also ensuring adequate space for teachers to design and reflect on their practices. Next year, I am planning a series of planning and initiation workshops to involve the Heads of science in co-designing school-based professional development for the next 2014 primary science syllabus so that they take greater ownership in theirs and their teachers' learning.

Overall, the research-based findings from the thesis will guide me in my professional work of designing curriculum, resources and professional development to support primary science teaching and learning. The EdD programme has also equipped me with the knowledge and skills to continue the enquiry and reflection as part of my professional practice to support teachers. Moving ahead, besides engaging teachers more in the curriculum development and implementation process, I would like to strengthen the inquiry science research-practice nexus. As a start, together with my specialist colleagues, we have initiated a network learning community "science inquiry in action" for specialists and primary science heads of department, master teachers and teachers. At this community, specialists and teachers come together to discuss research articles and reflect on classroom practices. Moving ahead, I hope to partner interested teachers to research on classroom practices in curriculum, pedagogy or assessment. These research-based findings can be used to inform curriculum design and implementation. I hope this is a start to a common vision and better partnership between specialists and teachers in developing the community of science teachers as good science professionals. (1929 words)

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Chapter 1

Introduction

This chapter provides the background for the study in the context of primary science education in Singapore (Section 1.1) as well as the rationale, purpose and significance of studying the process of how teachers learn and collaborate on using questioning to promote higher order scientific discourse (Section 1.2). The research question and definition of terms, as well as an overview of the following chapters are also presented (Section 1.3).

1.1   Primary science education in Singapore

In Singapore, the aim of primary science education is to provide students with experiences that build on their interest in and stimulate their curiosity about their environment. Through engaging in a variety of learning experiences, students construct basic scientific concepts as well as develop important skills, habits of mind, and attitudes necessary for scientific inquiry.

The thrust of science education in Singapore is encapsulated in the science curriculum framework from the Ministry of Education (Singapore) in Figure 1. Central to this framework is the inculcation of the spirit of scientific inquiry. The conduct of inquiry as understood here is founded on three integral domains: knowledge, understanding, and application; skills and processes; and ethics and attitudes, which are all deemed essential to the practice of science. Inquiry should be grounded in knowledge, issues and questions that relate to science in daily life, society, and the environment.
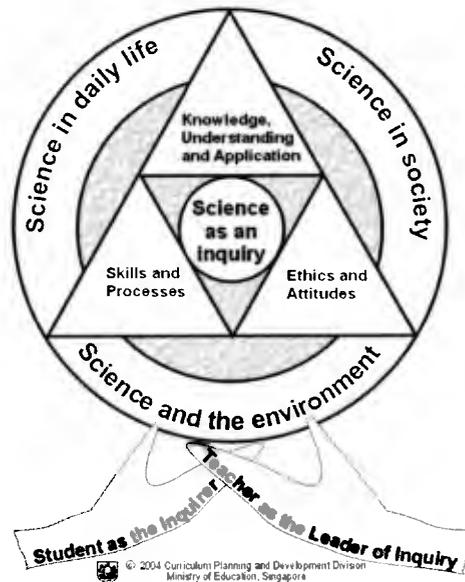
Figure 1. Science curriculum framework in Singapore (used with permission from Ministry of Education).

Scientific inquiry is central to the current primary science curriculum which is designed to emphasise teaching and learning approaches that nurture students as inquirers and critical thinkers. To be effective inquirers in the 21st century, students should be provided with opportunities to be critical thinkers, engaging in higher order scientific discourse in various contexts of inquiry activities which incorporate essential features of inquiry such as "questioning", "gathering evidence", "constructing explanations", "making connections", and "justifying explanations through communication" in the teaching and learning of science (National Research Council [NRC], 2000). Teachers are encouraged to use various strategies to incorporate these essential features of inquiry: in posing and responding to questions, designing investigations using evidence to support inferences, and evaluating and communicating their learning (student-directed inquiry) compared to the degree of involvement the teacher takes (teacher-guided inquiry).

With teachers as the key intermediaries between the curriculum and students, researchers and educators recognise the need to not only study the

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curriculum content that students need to know and the curriculum development process (Hart, 1989; Marsh, 2009) but understand different aspects of curriculum implementation. The key areas of research relating to curriculum implementation include the fidelity of curriculum implementation (Lee & Chue, 2011); the sustainability of curriculum (Campbell et al., 1994; Lynch, Pyke & Grafton, 2012); as well as teachers' concerns when implementing a curriculum (Anderson, 1997). Besides understanding the fidelity, sustainability and issues in curriculum implementation, there is also increasing emphases in understanding and supporting teacher learning and professional development (Clarke & Hollingsworth, 2002; Darling-Hammond & Bransford, 2005).

1.2   Rationale, purpose and significance of study

With the implementation of the new primary science curriculum in Singapore which is designed to emphasise teaching and learning approaches that nurture students as inquirers and critical thinkers, I am interested to explore how to better support teachers as a curriculum specialist-in-charge of planning and implementing the primary science curriculum. In order to support teachers, I need to understand teachers' process of learning and how to initiate changes in their knowledge, belief and practice necessary for curriculum implementation.

While working alongside teachers to support science teaching and learning as a specialist-in-charge of the planning and implementation of the primary science curriculum, I have observed that while resources and training designed to support teachers may highlight the features of inquiry, key strategies such as questioning are sometimes not effectively used to encourage students to engage in higher order scientific discourse. Hence, in my study, I focus on supporting teachers in questioning to support students as inquirers and critical thinkers in scientific discourse.

Teacher questioning is also well recognised as an important determinant of quality classroom interactions (Wellington & Osborne, 2001). Science educators and researchers recognise the importance of studying teacher questioning not in isolation but using questions in scientific discourse to promote student learning and outcomes in different contexts of inquiry activities. Recently, we see research on questioning presented in terms of frameworks (Chin, 2007; Mortimer & Scott, 2000; van Zee et al., 2001). In this regard, I am particularly interested in exploring Christine Chin's (2007) questioning framework in the primary context as it was first developed in the context of secondary science in Singapore (see Appendix A). Her research provides insights into how individual questions are woven holistically to influence student responses and thinking as well as how questions can help achieve teachers' goals in science teaching and learning contexts. Besides, I find this framework useful because it not only describes the features of the four questioning approaches (Socratic questioning, verbal jigsaw, semantic tapestry and framing) but includes the different strategies that teachers use for each of the questioning approaches. This is a realistic reflection of actual questioning practices in everyday classrooms - different ways of using questioning approaches by different teachers. Further elaborations on the strategies of each questioning approaches are at page 11 in Chapter 2.

In my Institution Focused Study (IFS), I empirically studied how two teachers used questioning to promote students' higher-order scientific discourse in primary science classrooms in Singapore. I found out how Chin's (2007) four questioning approaches (Socratic questioning, verbal jigsaw, semantic tapestry and framing), first reported in secondary schools in Singapore, were used with six pedagogies (whole class discussion, investigation, game, role play, concept mapping and information technology) and associated with students' higher level of cognitive responses in the topic "Reproduction". In the IFS, I looked for evidence of high cognitive level of thinking in students' responses to teachers' questioning and classified the cognitive levels of student responses within the teacher-student discourse as high or low using the Revised Bloom's Taxonomy (Anderson et al., 2001).

Interestingly, while both teachers were observed to use a variety of questioning approaches, they were not fully aware of and did not plan questioning approaches though they planned a few specific questions. While research studies have highlighted how teacher questioning can potentially stimulate students' higher order thinking (Chin, 2004), questioning, like other beneficial strategies, does not guarantee students' learning. This can be due to a multitude of complex and inter-related mitigating reasons that involve the teacher, learner, and the social/physical surroundings such as the teachers' understanding, beliefs, and practice (Spillane, Reiser & Reimer, 2002).

As I introduce teachers to typologies of questions such as the teacher questioning approaches that stimulate thinking (Chin, 2007) to promote higher order scientific discourse; I also need to understand the initial process of teacher learning and use of questioning in practice with other teachers. Hence, in the thesis, I can explore how teachers learn and collaborate to plan and use questions to promote higher order discourse in different contexts of inquiry activities. A study in this area is valuable as Darling-Hammond and Bransford (2005) highlighted that there is still a lack of research on how teacher learning affects teaching practices/student outcomes as well as how they learn successful practices. Besides, a recent review by Capps, Crawford and Constas (2012) also reveals the lack of empirical literature on inquiry professional development.

1.3 Research question and overview of chapters

My research question is thus, "How do teachers learn and collaborate during the initiation of a professional development programme focusing on questioning to promote higher-order scientific discourse in primary science classrooms?".

Teacher learning and collaborating refer to learning both individually and with others. This includes involving teachers in first reflecting on the questioning

typologies as well as examples of teaching and learning individually, before discussing reflections with other teachers at the questioning workshop. Beyond the workshop, teachers work with each other to develop and apply knowledge and skills of questioning in lesson design and practice for different topics and contexts of inquiry activities before customising the lessons for their individual classes. Besides lesson planning and customising, teachers also reflect on lesson design and use of questioning in promoting higher order scientific discourse individually and together with other teachers. Questioning here is confined to the four approaches from Chin's (2007) questioning framework (Socratic questioning, verbal jigsaw, semantic tapestry, framing). Scientific discourse refers to verbal interactions on science ideas or concepts between teacher-student(s) and student(s)-student(s), recognised as a means of communicating science.

In Chapter 2, I first discuss the broad trends in teacher education research and compare with trends in science teacher education research in the context of newer visions of professional development (Section 2.1). This sets the background for discussing teachers as reflective and collaborative learners in science teaching and learning contexts to promote constructivist or inquiry-based teaching and learning outcomes (Section 2.2). To understand and analyse teachers' process of learning, I will also discuss some existing models of teacher change and growth (Section 2.3).

In Chapter 3, I confirm the research question, arising from the rationale and context of study in the introduction chapter as well as issues explored in the literature review chapter (section 3.1). I will then discuss how the theoretical framework (section 3.2) and methodology (section 3.3) are appropriate for addressing the research question. Details of the conduct of the study such as the setting and participants, procedures, data collection and data analysis will then be presented. The political and ethical issues (section 3.4) for this study will also be discussed at the end of this chapter.

In Chapter 4, I first describe teachers' learning journeys (section 4.1) using evidence of teachers' enactment and reflection on questioning across various learning experiences (from the workshop participation to lesson conduct

and post lesson discussion) before presenting the case study of each teacher and mapping each teacher's change sequences and growth network (section 4.2). Finally, comparisons of teachers' change and growth are presented and discussed (section 4.3).

In Chapter 5, I discuss the development of the school-based professional development model (Section 5.1), in particular how teachers learn and collaborate in using the questioning framework of Chin (2007) to promote higher order scientific discourse; as well as how the model of Clarke and Hollingsworth (2002) was used as a tool for analysing the process of teacher reflection and enactment as learners in questioning – its values and limitations. I also draw conclusions on features of school-based professional development (Section 5.2) and propose implications for curriculum developers and school practitioners on the design of professional development for teachers in questioning to support science teaching and learning (Section 5.3). Finally, I highlight how this study contributes to knowledge of teacher learning and professional development (Section 5.4); as well as the limitations of the study and implications for future research (Section 5.5).

In summary, this chapter has established the background, rationale, purpose and significance of this study. With the implementation of the new Primary Science Curriculum designed to nurture students as inquirers and critical thinkers, this research is timely to foster a deeper understanding of the process of teachers' learning and practice in questioning in order to better support teachers in curriculum implementation. This study on teachers' initial learning and collaboration on questioning will also contribute to the research community as there is a lack of empirical literature on how teacher learning affects teaching practices as well as how teachers learn successful practices. The findings from this study will complement our present knowledge base and methods in merely using professional development to effect changes in teacher practices, particularly in teacher questioning. These insights will be valuable to both school practitioners

and curriculum developers in designing professional development opportunities and resources to support teachers in curriculum implementation, particularly in the area of teacher questioning.

Chapter 2

Literature Review

In this chapter, I discuss the broad trends in teacher education research and compare these with trends in science teacher education research in the context of newer visions of professional development (Section 2.1). This sets the background for discussing teachers as reflective and collaborative learners in science teaching and learning contexts to promote constructivist or inquiry-based teaching and learning outcomes (Section 2.2). To understand and analyse teachers' process of learning, I will also discuss some existing models of teacher change and growth (Section 2.3).

This literature review helps me in understanding what and how others have studied teacher learning and collaboration. It is also useful in developing my research question and method of inquiry to explore how teachers learn and collaborate in primary science classrooms in Singapore, particularly in the use of questioning to promote scientific discourse. It also affirms the value and contribution of my study to both the academic and professional fields.

2.1 Trends in teacher education and science teacher education research

2.1.1 Teacher education research

As teachers play key roles in the teaching and learning process, there has been emphasis in the literature on teacher education and research, particularly on what can help teachers learn or develop effectively (Garet et al., 2001). Darling-Hammond and Bransford (2005) highlighted four types of research on teacher education: (1) basic research on learning, development, language acquisition and

social contexts; (2) research on how learning conditions and teacher practices influence learning; (3) research on how teacher learning affects teaching practices and student outcomes; (4) research on how teachers learn successful practices. This typology of teacher education research is useful as it identifies the key areas of research on teacher education. More importantly, the classification serves to highlight the lack of research in the latter two areas on how teacher learning affects teaching practices / student outcomes as well as how they learn successful practices. The lack of studies in these two areas could be due to the complexity of teacher learning and practice in the social setting of their classrooms. While the complexity of teacher learning may have posed challenges to exploring the process of learning, studies to better understand teacher learning and practice in their school contexts would be important in informing the design of professional development for teachers.

2.1.2 Science teacher education research

The typology of teacher education research by Darling-Hammond and Bransford (2005) is also useful in understanding the types of science teacher education research. As I am interested in understanding how teachers learn and collaborate in using questioning to promote higher order scientific discourse, I will focus on discussing research studies which are related to the areas of questioning, discourse and teacher learning in science.

Just as Darling-Hammond and Bransford (2005) have found in their typology of teacher education research, I also found more basic research on learning, especially research on classifying cognitive processes. Bloom's taxonomy (Bloom et al., 1956), recently revised to encompass both knowledge and cognitive domains (Anderson et al., 2001; Forehand, 2005), was one of the first taxonomies used for designing and classifying questions to target different levels of thinking. Other taxonomies that were used to distinguish between recall

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and higher-level thinking operations include the taxonomy of Aschner, Gallagher, Perry and Afsar (1961) of recall, convergent, and divergent questions, Marzano's Taxonomy (1993) of recitation and construction questions as well as Walsh and Sattes's Taxonomy (2003) of recall, use, and create questions. Most of these taxonomies, including the original Bloom's taxonomy, were conceived with the purpose of classifying what was intended for students to learn often in a hierarchy of increasing complexity. Furst (1994) pointed out that a weakness of such hierarchies lies in the assumption that cognitive processes are ordered on a single dimension of simple to complex behaviours. Furst's views remind us that while taxonomies can facilitate teachers in designing and classifying questions to develop different cognitive processes in students, it would be valuable to study actual teaching practices to better understand how teachers use questions in scientific discourse to develop the various cognitive processes which may not necessarily occur in a linear hierarchy from simple to complex.

Increasingly, researchers are interested in studying actual teaching practices, particularly on how teachers' questions promote higher level thinking in constructivist or inquiry-based classroom contexts where questioning is seen as an essential feature of inquiry (NRC, 2000). These studies belong to the second type of research highlighted by Darling-Hammond and Bransford (2005), where researchers examine how teacher practices influence learning. For instance, Elder and Paul (2002) spoke of "essential questions" to focus students on reasoning while Chin (2004) used different types of questions to develop different process skills such as observing, comparing, classifying, communicating, analysing, investigating, creative problem solving and decision making. These studies have examined how different types of questions have developed student outcomes such as process skills and thinking. The process skills and thinking are valued in a constructivist or inquiry-based class where students are engaged in questioning, collecting and analysing evidence, constructing explanations, making connections and communication (NRC, 2000).

Underlying these studies of how teacher questioning influences student learning is Vygotsky's (1978) sociocultural theory of learning where learning is

mediated by "socialisation", between the teacher and students as well as between students and students. Wells and Chang-Wells (1992) described how learning can be mediated by the teacher who has to decide when, what, and how to contribute to and monitor children's talk. To understand how teachers mediate science classroom talk, Lemke (1990) identified patterns in science classroom dialogues and described three dialogue strategies, namely the triadic dialogue, retroactive recontextualisation, and joint construction. Among the three, the triadic dialogue of "teacher initiation/question", "student response" and "teacher evaluation" (IRE) (Mehan, 1979) was found to be the predominant pattern of interaction in science classrooms, including Singapore classrooms (Luke, Freebody, Lau, & Gopinathan, 2005). A common concern is whether the evaluative questions of the IRE format may be counterproductive to students communicating their thinking (Dillion, 1982). While other variations of the triadic dialogue such as IRF (Initiation, response, and follow-up) (Sinclair & Coulthard, 1975), IRP (Initiation, response, and prompt) (Scott, Mortimer & Aguiar, 2006) and IRPE (Initiation, response, prompt, and evaluation) (Eshach, 2010) have been reported, researchers highlight the need for more deliberative or dialogic discourse in the science classrooms (Mortimer & Scott, 2003; Simon, Erduran & Osborne, 2006). Hence, it would be useful to find out how teachers can be supported in learning and using questioning to bring about higher order scientific discourse beyond the commonly cited IRE and its variations of scientific discourse reported so far.

While studying the patterns of scientific discourse, Mortimer and Scott (2003) noticed that the teachers' purpose of questioning, structure of questioning sequence, nature of questions and responses in a constructivist or inquiry-based class are different from traditional science classes. Their findings were supported by Ruiz-Primo and Furtak (2006) who found teachers using questions as an informal formative assessment to draw out and act on students' understanding. To better understand the interactions between both teacher and student moves in contructivist or inquiry-based science classrooms, Chin (2006) developed a "questioning-based discourse" analytical framework; this includes the forms of utterance (e.g. I, R, and F), purpose of utterance (elicit, reply, probe and extend)

as well as the types of utterance (e.g. question, statement or comments). She later extended this work to develop a framework of questioning approaches - Socratic questioning, verbal jigsaw, semantic tapestry and framing (Chin, 2007) used by teachers to scaffold students' thinking and help them construct scientific knowledge. I find this framework useful as it reflects the different strategies used by teachers within each questioning approach, recognising that different teachers may use each of the questioning approaches differently. For instance, in Socratic questioning, teachers used a series of questions to prompt and guide student thinking through different strategies such as "pumping", "reflective toss" or "constructive challenge". For verbal jigsaw, teachers focused more on the use of scientific terminology, keywords and phrases to form integrated propositional statements using strategies of "key word and phrase association" or "verbal cloze". In semantic tapestry, teachers helped students weave disparate ideas together into a conceptual framework through strategies of "multi-pronged questioning", "stimulating multimodal thinking" or "focusing and zooming". Finally, for framing, teachers used questions to frame a problem, issue or topic to structure students' discussion and the strategies include "question-based prelude", "question-based outline" or "question-based summary". Details of the four questioning approaches and the strategies within each questioning approach are at Appendix A.

While Chin's (2007) framework of questioning approaches contributes to an understanding of how different individual questions can be woven holistically into instruction to stimulate thinking, the framework focused more on their particular features/functions. I am interested in how teachers learn and use the four questioning approaches, first identified in Singapore secondary science classrooms, in the inquiry contexts of their own classrooms at the primary level.

So far, the studies we have discussed on the area of questioning and scientific discourse focus more on how teacher questioning influence student thinking. While these studies have led to better understanding of teachers' questioning practices and patterns of scientific discourse, there are still fewer studies on how teacher learning affects teaching practices and student outcomes

as well as how teachers learn successful practice. These two areas of study belong to the third and fourth types of research on how teacher learning affects teaching practices / student outcomes as well as how they learn successful practices highlighted by Darling-Hammond and Bransford (2005). They can provide insights into the process of teachers' ongoing learning within communities of learners as they are teaching. This is an area which is gaining prominence with newer visions of professional development (Darling-Hammond & Bransford, 2005; Loucks-Horsley et al., 2003). My study on how teachers learn and collaborate in using questions to promote higher order scientific discourse will provide insights into the process of how teacher learning can initiate changes in their questioning practices; as well as how teachers learn successful practice.

2.2 Teacher change: as collaborative and reflective learners

2.2.1 Teacher change as learning

The newer vision of professional development shifts the focus to teacher change in ongoing learning experiences and practice. There are different perspectives on teacher change, including change as training, change as adaptation, change as personal development, change as local reform, change as systematic restructuring or change as growth or learning (Clarke & Hollingsworth, 2002).

For the purpose of my study, I am interested in teacher change as growth or learning, individually and in collaboration with other teachers in the school setting. The emphasis on growth or learning, represents a shift from simplistic or mechanistic views of teacher change to more complex and sustained change. Fraser, Kennedy, Reid and Mckinney (2007) also perceive teacher change as a process of learning. They describe teacher change as transactions between teachers' knowledge, experience and beliefs and professional actions. Such

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transactions need to be considered when providing experiences that help to develop knowledge that teachers can draw on in their practice. The complexity of teacher learning is acknowledged by Simon and Campbell (2012), who conceptualise teacher learning as a complex combination of individual teacher's knowledge growth, the professional teacher practicing in a particular setting and the social teacher working with others in the setting. Such notions of complexity are important in this study as it is envisaged that enhancing questioning for higher order scientific discourse relies on development of new knowledge that arises from outside sources in conjunction with practice that is situated in teachers' own contexts.

2.2.2 Teacher learning – Principles, conditions, framework and strategies of learning

In effecting teacher change, researchers have recognised the limitations of "one-off" workshops targeted at teacher mastery of knowledge and skills (Fullan and Stiegelbauer, 1991; Guskey, 1986). A common challenge is in bringing teachers' professional development experiences closer to the realities of their classrooms; bridging the gap between theory and practice. Some researched on the principles of learning - to engage teachers' preconceptions; develop their own conceptual framework of knowledge and understanding; and use a metacognitive approach to enable them to better handle classroom complexities (Hammerness et al., 2005). While these principles of learning highlight how people learn and can guide the design of professional development, the conditions of learning are not explicitly highlighted in these principles of learning. It is important to consider the conditions for teacher learning (Hoban, 2002) as teacher learning is complex, involving learning in conditions that are unique and situated in teachers' own school and classroom contexts.

Hoban (2002) has studied the conditions for teacher learning which include: teaching as a dynamic relationship with students and other teachers; room for reflection; sense of purpose; a community to share experiences; opportunities for action; expert input to extend teachers' knowledge and experience; feedback from students; as well as sufficient time to adjust to changes. Like Hoban (2002), Adey (2004) identified factors that not only help learning, but also sustain practice such as ownership, motivation to change and collegiality. The conditions and factors highlighted by Hoban (2002) and Adey (2004) remind us of the complexity of teacher learning. It would also be valuable to better understand how teachers learn, individually and with others, under different conditions and factors in the actual school and classroom contexts.

To make sense of the complexity of teacher learning, Hammerness et al. (2005) developed a framework to capture the various aspects of teacher learning. They suggested that teachers learn to teach in a community that enables them to develop a vision for their practice; a set of understandings about teaching, learning and children; dispositions about how to use this knowledge; practices that allow them to act on their intentions and beliefs; as well as tools that support their efforts. In this framework, the process of teacher development is not seen as going through a series of stages but rather the emphasis is on the inter-relationships between teachers' learning and the context of learning – how learning unfolds in contexts that promote learning. While this framework has incorporated the principles of learning and highlighted the importance of inter-relationships between different aspects of teachers' learning in context, the framework has its limitations as it does not represent the inter-relationships between the various aspects of teacher learning processes explicitly.

While the principles, conditions and framework of teacher learning developed so far have provided insights into the important aspects of teacher learning, it would be valuable to better understand how teacher learning and practices take place in the actual ecology of the school community and classrooms. Loucks-Horsley et al. (2003) identified cluster of strategies supporting teachers'

learning and practice. These include: aligning and implementing curriculum materials with opportunities to reflect; collaborative structures; examining teaching and learning through action research and case discussion; immersion experiences where teachers benefit from engaging in activities designed for student learners; practising teaching through coaching, mentoring and demonstration lessons; as well as courses, workshops and strategies for developing professional developers. While each cluster of strategies may be useful in teacher learning, more research into how the various strategies can be organised or sequenced to support teachers in learning and in practice would provide useful insights into the relationships between the strategies for designing teacher professional development.

Regarding the use of the strategies, Guskey (2000) proposed that a combination of different strategies should be included in professional development plans to take advantage of the positive attributes of each strategy. Like Guskey, Putnam and Borko (2000) also highlighted the need to situate teachers' learning using different strategies and that the goal for teacher learning is important in determining the choice of strategies. For instance, experiences at workshop settings can develop new insights about subject matter and student learning. Experiences situated in the teachers' own classrooms can facilitate teachers' enactment of specific instructional practices. They recommended a combination of strategies situated in a variety of contexts to foster multidimensional changes in teachers' thinking and practices; as well as further research to better understand the complex dynamics of the different strategies to teacher learning. The challenge would be how to embed the various strategies as learning opportunities in teachers' school and classroom practice and understanding how teachers engineer their own learning process.

So far, different combinations of strategies are observed in different studies. For instance, Borko et al. (1997) have reported teachers enacting ideas from materials and activities introduced at a workshop session in their classrooms and discussing their experiences in subsequent workshop sessions. Others have

designed case-based learning experiences for teachers, providing shared experiences for teachers to explore and reflect on the richness and complexity of genuine classroom settings (Felto vich, Spiro & Coulson, 1997). In some cases, external parties such as researchers are involved to initiate change in some cases or bring about sustained implementation in others. For instance, Jones et al. (1992) studied how teachers worked alongside researchers to negotiate a starting point for developing, planning, reflecting and evaluating changes to implement more inquiry-based activities in a new curriculum. While different studies have focused on employing different combination of strategies to engage teachers as learners, it would be valuable to better understand teachers' roles as learners in the learning process and how they can play a more active role as a learner, collaborating and reflecting to meet their own learning needs and interests.

2.2.3 Teacher learning as an active process of collaboration and reflection

In the various strategies of learning discussed to effect teacher change, teachers are seen as active learners, engaged in collaborative and reflective practice. Hence, change is not something that is done to teachers but change as a process that involves learning (Fullan and Stiegelbauer, 1991; Teacher Professional Growth Consortium, 1994).

Putnam and Borko (2000) highlighted that the interactions with people are major determinants of both what is learned and how learning takes place. Some teachers may not have specialised in a science-related discipline. Others may not have experienced learning science as an inquiry in the student-centred classroom themselves (Windschitl, 2002). Hence, when teachers with different types of knowledge and expertise come together to collaborate, they can draw on each other's expertise to create rich conversations and develop pedagogical skills for inquiry-based instruction and beliefs in keeping with the philosophy of inquiry. So far, the role of collaboration in supporting teachers' learning is widely

documented (Bell & Gilbert, 1996; Clarke & Hollingsworth, 2002; Shulman & Shulman, 2004), but there is little distinction between the nature of collaborative learning as "collaborative culture" or "contrived collegiality" (Hargreaves, 1994). Besides, there are few empirical studies on the nature of collaboration and how they contribute to professional learning (Simon & Davies, 2012). This idea of learning together through collaboration is important in this study as it would provide teachers with opportunities to enact, reflect and discuss each other's questioning practices to promote higher order scientific discourse in students. So far, Singapore teachers have many opportunities to participate not only in science professional development workshops but professional learning communities based on the idea of communities of practice (Lave & Wenger, 1991). However, there is limited understanding on whether teachers learn, what they learn and how they collaborate in applying and reflecting on what they have learned in practice beyond the workshops. Insights into collaboration practices and how they contribute to professional learning will inform schools in future design of opportunities to promote teacher learning at and beyond workshops with other teachers.

Besides providing platforms for collaboration, many recognise the importance of embedding opportunities for teacher reflection (Schon, 1983) on their learning at professional development and how they could apply their learning to their own classroom practice (Lewis et al., 2011; Monet & Etkina, 2008). While different types of reflections such as "knowing-in-action", "reflection-in action" and "reflection-on action" have been observed, some still question what it means to be reflective (Hatton & Smith, 1995; Orland-Barak, 2005) while others observe limited opportunities in professional development sessions for meaningful reflection and growth (Ball, 1994). A common question remains on how much structure and guidance should be provided during teachers' conversations and how to provide a balance between setting direction for a desired change and empowering teachers in determining their changes (Richardson, 1992). To support teachers' reflection, Kramarski and Michalsky (2010) found that metacognitive support using self-questioning enhances

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teachers' ability to reflect on their learning processes, both as learners and teachers. Besides self-questioning, Shulman and Shulman (2004) also highlighted the value of shared meta-cognitive reflection where teachers critically discuss and reflect on their work with each other. To capture and share the learning process, Simon and Johnson (2008) used portfolios for argumentation in professional development programme, helping teachers apply their learning and share reflective analysis of practice with other teachers. All these studies have provided teachers with opportunities not only to reflect individually but share reflections with other teachers. Besides these considerations, it will also be important to consider how to strike a balance between setting direction for a desired change through external stimuli and empowering teachers in determining their own changes when reflecting on questioning practice in this study. The latter can also be influenced by teachers' own knowledge and beliefs about questioning.

To facilitate collaboration and reflection, the analysis of teacher learning and practices using video cases has gained importance. Videotapes of classrooms are used as springboards for the analysis and dialogue of teaching and learning (Brophy, 2004; Darling-Hammond & Bransford, 2005; Richardson & Anders, 1994). Oliveira (2010) engaged teachers in video-based discourse analysis, contextualised reflection and argumentation about their own questioning practices. Besides using videos to study teachers' practices, Seidel et al. (2011) compared the effects of analysing videos of one's own versus others' on teacher learning, particularly on knowledge activation and professional vision. They reported that teachers who analysed their own teaching experienced higher activation – higher immersion, resonance and motivation. The use of both one's own and others' videos would be relevant in this study so that teachers can analyse, discuss and reflect individually and with other teachers on how questions have facilitated students' higher level of thinking within scientific discourse in each other's classes.

While researchers have explored different ways to structure professional development to facilitate teacher learning to encourage collaboration and

reflection, the understanding of the mediating processes of teachers' learning in and across different learning experiences is still limited. In my study, I am interested in studying the processes of how teachers learn and collaborate on questioning from their participation at the workshop to enactment in their classrooms to reflection on practices. It is thus useful to find out what others have done to analyse and describe teachers' process of change in the next section; to inform the method of inquiry for my own study - how I can analyse teachers' learning and represent their changes or growth in this study.

2.3 Process of teacher learning - change and growth

To better understand the process of teacher change in the actual ecology of the school and classrooms, some researchers have identified different types (or domains) of development based on data to describe how teachers change over time. For instance, Bell and Gilbert (1996) described three types of development (social, personal and professional) which occur within components of support, feedback and reflection specifically for science teacher development programmes. For each type of development, three main aspects of learning are identified. For example, for social development, teachers may initially see isolation as problematic. They may progress to valuing ways of working and reconstructing what it means to be a teacher of science and value working with other teachers. Overtime, they may initiate ways of working with others. These models of teacher development remind us that while the types of development may be defined, teachers' actual development may not follow a fixed sequence in the actual learning process and may vary from teacher to teacher too.

Hence, others try to understand the actual process of teacher change by identifying change domains and studying the relationships between them. The common change domains which are studied are the knowledge and practice domains, in particular the interplay between teacher knowledge and practice, now

represented as a typology of "knowledge-for-practice", "knowledge-in-practice", and "knowledge-of-practice" (Cochran-Smith & Lytle, 1999). Goodnough (2010) used this typology to examine the relationships between teacher knowledge and practices, providing insights into the nature of teacher learning and practice. Others, such as McMeniman et al. (2000) try to further understand teacher learning, by exploring teachers' roles as learners and as collaborators. This attempt to understand teachers' learning with others is also important in this study as it will help in the understanding how teachers' knowledge can be socially constructed with others and in practice.

Others go beyond just examining the relationship between teacher knowledge and practice to include other domains of changes and mediating processes of change. The interconnected model of teacher professional growth (Clarke & Hollingsworth, 2002; Clarke & Peter, 1993; Teacher Professional Growth Consortium, 1994) in Figure 2 is one of the few models that suggests how change occurs through the mediating processes of "reflection" and "enactment" in four distinct domains: the personal domain (teacher knowledge, beliefs and attitudes), the domain of practice (professional experimentation), the domain of consequence (salient outcomes), and the external domain (sources of information or stimulus). The mediating processes of reflection and enaction are represented in the model as arrows linking the domains. For instance, the external stimuli can prompt teachers' enactment in practice and changes in their personal domain. Teachers' reflection on their practice can lead to changes in the domain of consequences and reconstruction of their personal knowledge, beliefs and attitudes. Hence, this cyclical model is useful in understanding the process of teachers' learning and collaboration in this study.
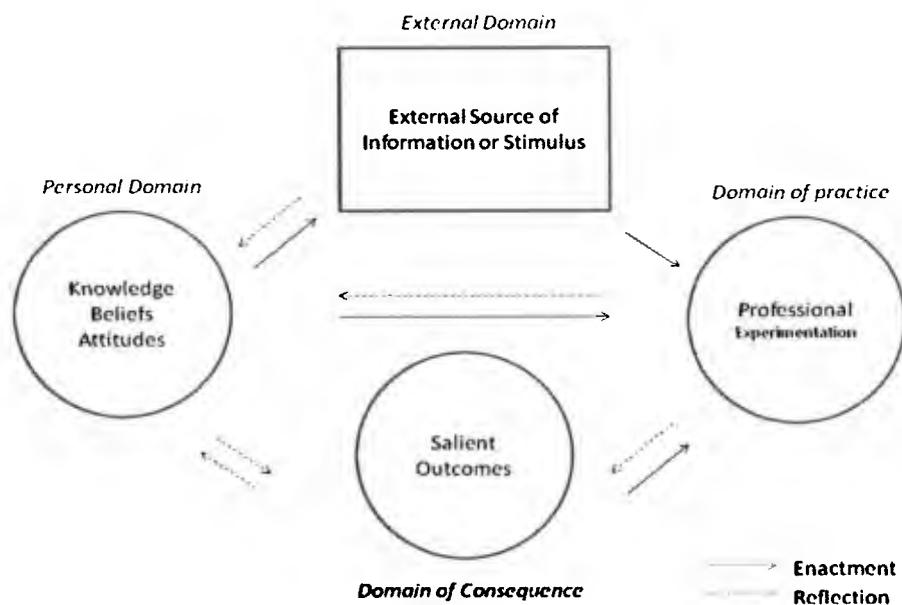
Figure 2. The interconnected model of professional growth

Clarke and Hollingsworth (2002) also provided empirical grounding of the interconnected model by reporting teachers' change of ideas or practices. They used evidence of teachers' exploration of strategies and activities and reporting of ideas. The process by which change occurs was represented as the "change sequence", consisting of two or more domains together with reflective and enactive links connecting these domains. A change sequence associated with more lasting change is termed a "growth network". I am particularly interested in this model as I can understand how teachers learn and collaborate by analysing the domains of change and mediating processes. The change sequences or growth networks for each teacher can be mapped to gain insights into how each teacher learn (enact and reflect) to question across the various planned learning experiences, from the questioning workshop to the post lesson discussions.

In summary, the literature review has provided an overview of trends in teacher education and science teacher education research with newer visions of professional development and changing roles of teachers in the learning process. The review has identified a lack of empirical literature on how teacher learning affects teaching practices as well as how teachers learn successful practices. My study on how teachers learn and collaborate in using questioning to promote higher-order scientific discourse in primary science classrooms will provide empirical evidence on teachers' learning, in particular their roles as reflective and collaborative learners in the social context of their own schools and classrooms. It will also provide insights into how teacher learning can initiate changes in their practices, contributing to both academic knowledge and professional practice.

Chapter 3

Theoretical and Methodological Perspectives

In this chapter, I confirm the research question, arising from the rationale and context of study in the introduction chapter as well as issues explored in the literature review chapter (section 3.1). I will then discuss how the theoretical framework (section 3.2) and methodology (section 3.3) are appropriate for addressing the research question. Details of the conduct of the study such as the setting and participants, procedures, data collection and data analysis will then be presented. The political and ethical issues (section 3.4) for my study will also be discussed at the end of this chapter.

3.1 Research question and definitions

Based on the rationale and context of study in the introduction chapter as well as issues explored in the literature review chapter, my research question is "How do teachers learn and collaborate during the initiation of a professional development programme focusing on questioning to promote higher order scientific discourse in primary science classrooms?" The various terms in the research question including "teacher learning and collaborating", "questioning" and "scientific discourse" were already defined in Chapter 1 (page 5).

3.2 Theoretical framework

The theoretical framework underlying my study is social constructivism, focusing on teacher learning, individually and with others, to promote higher order scientific discourse in the context of inquiry activities in primary science classrooms. Central to Vygotsky's (1978) sociocultural theory of learning is how

learning is mediated by other people and cultural artefacts, including physical objects (e.g. textbooks and the Internet) and social processes (e.g. various pedagogies). This theory supports what I am interested to explore in this study: structuring learning experiences (for teachers working individually and with others) in questioning and studying the process of teachers' learning as they initiate changes in practice in questioning to promote higher order scientific discourse. As teachers' learning is social, the roles of others including teachers and students in the learning process need to be considered (Smidt, 2009). In the learning process, teachers may build on their own prior knowledge and experiences as well as learn when interacting with other teachers during the enactment and reflection of questioning practices. As it is often said of Vygotsky's work; learning leads development and that learning appears between people on an interpsychological plane and inside the learner on an intrapsychological plane. This has implications on how learning experiences are purposefully designed for teachers to engage, enact and reflect on using questions to promote scientific discourse.

Figure 3 shows a framework of teacher learning and collaboration in teacher questioning, which I have designed based on the principles of how people learn. The framework comprises three concentric rings. For each ring, I have included considerations on how teachers learn individually and with other teachers. In the first (innermost) ring, each teacher's knowledge and beliefs on teacher questioning are engaged using questioning typologies and examples of teaching and learning as learning stimuli. Each teacher reflects individually before sharing their reflection with other teachers. In the next (middle) ring, teachers are provided with opportunities to work together to develop and apply knowledge and skills by co-planning lessons together before customising and enacting questioning individually for different topics and contexts of inquiry activities. In the third (outermost) ring, teachers reflect on lesson design and use of questioning in promoting higher order scientific discourse individually before sharing their reflections with other teachers.

Overall, the framework is useful for this study as it provides a guide in designing learning experiences for individual and groups of teachers, from engaging their prior knowledge to enacting and reflecting on their practice in promoting higher order scientific discourse. Teachers' learning experiences across the three rings should not be seen as distinct phases but a continual process of learning, where teachers go through cycles of enactment and reflection. As different teachers may enact and reflect in different ways, I have not included arrows to illustrate possible enactment and reflection in this framework. The actual enactment and reflection of each teacher will be presented in Chapter 4, using the interconnected model of professional growth (Clarke & Hollingsworth, 2002) as an analytical tool.

Reflect on lesson design and use of questioning

Reflection with
others

Develop and apply knowledge and skills - enact questioning in practice

Planning and use of questions
for different topics and contexts with others

Engage knowledge and belief on questioning

Learning with others

Framework for Learning and Collaboration in Teacher Questioning

Individual
learning

Individual customisation of questions
for different students and contexts

Individual
reflection

Learning with Others

Individual Learning

Figure 3. Framework for learning and collaboration in teacher questioning

3.3 Methodology

To explore the research question "How do teachers learn and collaborate during the initiation of a professional development programme focusing on questioning to promote higher order scientific discourse in primary science classrooms?", I provided four voluntary teacher participants with the opportunity to learn individually and with each other on questioning in the social setting of their own school. The common learning experiences ranged from participating in a school-based questioning workshop; to planning, conducting and reflecting on questioning practices / scientific discourse with other teachers using their own classroom videos and lesson transcripts.

To understand each teacher's learning process, I used a qualitative approach to explore how each teacher initiated their learning and collaboration in using questioning to promote scientific discourse by analysing the teachers' workshop discussion, lessons and post lesson discussions to find evidence of learning and collaboration. The design of this study has features of a case study research design where detailed information is collected using a variety of data collection procedures. This allows a program, event, activity or process of one or more individuals to be explored in depth (Creswell, 2009; Yin, 2003). While there are variations of case study as a research method, I am interested to study in depth, how four teachers initiate their learning individually and with other teachers in the real-life contexts of the school and classrooms. Hence, I am using a multiple-case design, comprising four cases but limiting the scope of the cases to how each teacher initiates his or her learning. The multiple-cases enable the in-depth study of each teacher, recognising the idiosyncratic and individual nature of teacher professional learning within each case study. At the same time, I can compare across the case studies to understand the similarities and differences between the initial learning processes of four teachers.

As learning is complex and takes time (Fullan, 2001), the aim of this study is to find out how each teacher initiated changes in questioning practices within

the period of six months of this study. With this objective in mind, the model of Clarke and Hollingsworth (2002) is useful as it allows mapping of change sequences and growth networks of how each teacher learns and uses the questioning framework of Chin (2007) to promote higher order scientific discourse over the period of study. Details of the conduct of the study including the setting and participants, procedures, data collection and analysis are presented next.

3.3.1 Setting and participants

Given my role in developing the primary science curriculum and supporting teachers in implementing the curriculum, I work closely with schools to understand how to better support teachers and students in the teaching and learning of science. I first sought the consent of the Principal of a nearby school which was representative of a typical Singapore government / public primary school to carry out my research. Next, I invited Primary Four and Five science teachers to take part in the research. Four teachers (Teachers G, J, A and Y) volunteered to participate in the study. Teachers G and J taught the Primary Four level (students of age 10) while Teachers A and Y taught the Primary Five level (students of age 11). They were assured of the confidentiality of their identities and that they could withdraw from the study at any point of the study. Table 1 below shows an overview of the educational and professional background of the four teachers.

Table 1

An overview of educational and professional background of Teachers G, J, A and Y

Teacher	Sex	Years of teaching experience	Years of teaching science	Educational and other background
G	Male	29	1	A level certification; Diploma in Education (General); Previous Head of Physical Education
J	Female	2	2	A level certification; Diploma in Education (General)
A	Male	11	11	BSc in Chemistry; Post Graduate Diploma in Education; Head of Science
Y	Female	3	3	BSc (Biology) with Diploma in Education

Teacher G is an experienced teacher of 29 years. He was also the previous Head of Department for physical education and has been teaching mainly physical education across various levels in the school. Besides physical education classes, he was also deployed to teach science in a Primary Four (Grade Four, age 10) middle ability class. When introducing himself at the questioning workshop, he said that he was a "new teacher" in science teaching.

Teacher J is a new teacher who is second year in service, a member of the science committee and form teacher of a Primary Four (Grade Four, age 10) high ability class. She previously held an administration job and decided to teach as she enjoys interacting with young children.

Teacher A is the Head of Department of Science since 2002, an experienced teacher of almost eleven years and form teacher of a Primary Five (Grade Five, age 11) middle ability class this year. He has also recently completed his Masters in Education and shared his interest in research on strategies affecting students' science achievement.

Teacher Y is a science graduate, a new teacher of three years and form teacher of a Primary Five (Grade Five, age 11) high ability class. She is a member in the science committee and enjoys supervising students' participation in science fairs and competitions. She is currently pursuing her Masters in Education, focusing on the use of technology in science teaching and learning.

3.3.2 Procedures

In view of my purpose in understanding teacher learning and collaboration in promoting higher order scientific discourse, I used a qualitative approach to make meaning of teachers' process of learning across various learning experiences. The design of this study has several characteristics of a qualitative research (Creswell, 2009). Firstly, I collected data in teachers' own school and classroom contexts – the data emerged close to everyday practices rather than obtained from laboratory settings. Secondly, I am the key research instrument, gathering multiple forms of data through teachers' workshop journals and discussions, lesson observations and post lesson discussions to find evidence of teachers' learning. Thirdly, I made emic interpretations of what I observed and understood, following closely to teachers' own accounts of enactments and reflections of questioning across different learning experiences to manage possible biases in the research. Triangulating my interpretations with teachers' own accounts of enactment and reflection is important because my role in developing the curriculum and supporting teachers in implementing the curriculum may influence my interpretations of what I observed. As I supported teachers in selected lessons and post lesson discussions, my interpretations of teacher learning were based on observations of how teachers were initiated into the professional development programme focusing on questioning to promote

higher-order scientific discourse across the workshop discussion, lesson conduct and post lesson discussions.

The teachers' learning experiences included participating in a three day workshop on "Questioning for learning and thinking in science inquiry context workshop"; conducting lessons that they planned at the workshop; and reflecting on lessons at post lesson discussions. I have designed these learning experiences to provide teachers with opportunities to learn, enact and reflect on questioning in their own school and classroom context over a period of six months. An overview of teachers' learning experiences is outlined in Figure 4.

Primary Four (Grade Four, age 10) teachers (G and J)	Primary Five (Grade Five, age 11) teachers (A and Y)
Participate in workshop on "Questioning for learning and thinking in science inquiry context" (Days one and two)	
↓	↓
Plan, conduct and reflect on teacher questioning and student thinking in four lessons from the topic "Heat"	Plan, conduct and reflect on teacher questioning and student thinking in four lessons from the topic "Plant Reproduction"
↓	↓
Participate in workshop on "Questioning for learning and thinking in science inquiry context" (Day three)	
↓	↓
Plan, conduct and reflect on teacher questioning and student thinking in four other lessons from the topic "Light"	Plan, conduct and reflect on teacher questioning and student thinking in four other lessons from the topic "Plant Processes"

Figure 4. An overview of learning experiences and opportunities of teachers

The four teachers first participated in a "questioning for learning and thinking in science inquiry context" workshop that I designed to initiate teachers in learning Chin's (2007) questioning approaches. At the first two days of workshop, the teachers:

- reflected on "what they know", "what they want to know" and "what they learn"

- shared their observations and beliefs on "inquiry", "learning and thinking" and "questioning" based on a common science video lesson

- shared their ideas on the roles of teacher questioning, examples of questions as well as how and when they are used

- analysed scientific discourse (teacher questioning and student thinking) in four science video lessons, before the introduction of Chin's (2007) questioning framework

- learned Chin's (2007) questioning framework of Socratic questioning, verbal jigsaw, semantic tapestry and framing by reading about each questioning approach individually before sharing learning points with other teachers

- analysed scientific discourse (teacher questioning and student thinking) in the same four science video lessons, after the introduction of Chin (2007) questioning framework

- planned lessons of their choices with other teachers and customised lessons individually

After the first two days of workshop, the pair of Primary Four teachers (Teacher G and Teacher J) conducted the four planned lessons on the topic "heat" and engaged in post lesson reflection and discussion. Similarly, the other pair of Primary Five teachers (Teacher A and Teacher Y) conducted four other planned lessons on the topic "plant reproduction" and reflected and discussed their lessons. At each post lesson reflection and discussion, teachers were invited to highlight parts of the lessons using videos / lesson transcripts for discussion. In the selected

scientific discourse segments, they analysed teacher questioning and student thinking.

The four teachers next participated in the third day of workshop where they:

- reflected on their own learning journey on questioning
- identified questioning approaches that they have learned, applied and impacted student learning
- presented a selected part of their own lessons on how they have used questioning and also shared in others' questioning experiences
- analysed scientific discourse (teacher questioning and student thinking) in different teaching and learning contexts in different topics
- planned lessons of their choices with other teachers and customised lessons individually

After the third day of workshop, both pairs of Primary Four and Five teachers conducted and engaged in post lesson reflection and discussion of another eight lessons from two topics of "light" and "plant processes" respectively. An overview plan of the workshop session and samples of workshop materials are at Appendices B and C respectively.

3.3.3 Data collection and analysis

During the period of study, I collected evidence of teachers' learning through different data sources, starting from the workshop. Besides collecting teachers' individual reflections in workshop journals, I also made audio recordings of teachers' discussions at the workshops. These workshop data provided useful insights on teachers' prior knowledge and belief on questioning as well as how they learned and reflected on the questioning framework and their existing practices individually and with other teachers.

After the workshop, I observed and videotaped Teacher G (four lessons) and Teacher J (four lessons) for the topics on "Heat" and "Light"; and Teacher A (four lessons) and Teacher Y (four lessons) for the topics on "Plant reproduction" and "Plant system". A total of sixteen lessons was observed, with each lesson lasting an average of one hour. The observations included introductory, development and concluding lessons covering different concepts in the four topics mentioned above. The teaching and learning in the classes included direct instruction, guided discussion, demonstration in whole class contexts, as well as small group hands-on activities and discussions. The purpose of observing these lessons was to understand how teachers enacted the questioning framework across different topics and lesson contexts. Teachers' use of the questioning framework in practice was an evidence of their learning. To facilitate the understanding of the lesson contexts in which the teachers have used Chin's (2007) questioning approaches, brief descriptions of each of the Primary Four and Primary Five lessons are presented in Tables 2a and 2b respectively. Each lesson description included the lesson intent (introductory, developing, concluding); lesson focus (conceptual, skill or attitudinal outcomes); as well as pedagogical and assessment strategies.

Table 2a

An overview of lessons conducted by Teachers G and J

Primary Four lessons	Description of lessons
Heat lesson (heat transfer)	This lesson was an introductory lesson to the concept of heat transfer. Both Teachers G and J used a whole class discussion and a demonstration to engage students in predicting and discussing heat flow based on observations of the heating of a metal rod with metal thumbtacks attached; before applying concepts in discussing heat transfer in everyday contexts. The lesson resources are at Appendix D.
Heat lesson (heat conduction)	This lesson was a follow-up lesson from the "Heat transfer" lesson. Both Teachers G and J used a whole class discussion followed by small group investigation using datalogger with temperature sensor to explore heat conduction in cups made of different materials: ceramics, metal and styrofoam. Students also discussed heat conduction in everyday contexts. The lesson resources are at Appendix E.
Light lesson (transparency of material)	This lesson was an introductory lesson where students investigated the transparency of different materials. A whole class discussion, followed by small group investigation, was used by both Teachers G and J to allow students to measure the amount of light that can pass through different types of materials using dataloggers and light sensors. The lesson resources are at Appendix F.
Light lesson (shadow formation)	This lesson was a follow-up lesson on "light transparency" on the concept of shadow formation. Both teachers G and J used a whole class discussion and small group investigation to find out how shadows are formed and explore forming different shapes and sizes of shadows by changing selected variables. The lesson resources are at Appendix G.

Table 2b

An overview of lessons conducted by Teachers A and Y

Primary Five lessons	Description of lessons
Plant reproduction lesson	This lesson was an introductory lesson to flowering plant reproduction comprising processes of pollination, fertilisation, germination and dispersal (wind, water, animal, explosive action). Both Teachers A and Y provided opportunities for students to role play, represent and explain their ideas of plant reproduction – the parts of flowers involved in the processes of plant reproduction. The lesson resources are at Appendix H.
Plant dispersal lesson	This lesson was a follow-up lesson, developed from the "plant reproduction" lesson. Both Teachers A and Y used a whole class discussion followed by small group investigation for students to explore fruits /seeds dispersed by different methods (wind, water, animal, explosive action). Students observed the characteristics of the fruits /seeds and infer on how they could be dispersed. The lesson resources are at Appendix I.
Plant transport lesson	This lesson was an introductory lesson to explore the plant transport system. A whole class discussion, followed by small group planning, was used by both Teachers A and Y to allow students to plan and set up investigations to show how water is transported in a plant. No worksheet template was provided.
Plant system lesson: An integration	The lesson on "plant system" was a concluding lesson on plant system. Both Teachers A and Y used a whole class discussion and small group discussion to provide students with opportunities to make connections between plant processes and concepts learned across topics/lessons. No worksheet template was provided.

In view of resource constraints and the availability of limited video recorders for use in each class, only classroom discourse in whole-class settings and in some cases, small group discussions were video-recorded. The latter were recorded whenever the teachers moved around to talk to individual groups of students. Two video cameras were set up: One at the back of the classroom was directed at the teacher and students while the other followed the teachers as they facilitated group work. The capture of teachers' questions in scientific discourse for both whole-class settings and small group discussions facilitated teachers' individual reflection and group discussion as well as analysis of scientific discourse (teachers' questions and students' thinking) in the two class settings, which are common in science classes in Singapore.

Besides observing and videotaping the lessons, I also conducted separate post lesson discussions with each pair of the Primary Four and Five teachers after each pair of lessons. During the post lesson discussions, the videos recordings and transcripts of lessons were shared with the teachers to facilitate individual and pair analysis of questioning and student thinking. After the post lesson discussions, teachers' discussions were also transcribed to facilitate analysis of evidence of learning through the teachers' reflections. At these post lesson discussions, I facilitated discussions by asking questions rather than answering or evaluating teachers' reflections on questioning practices and student learning. This is consistent with what I usually do as a curriculum specialist when facilitating workshop and lesson discussion to support teachers in curriculum implementation.

Hence, the data sources included teachers' workshop journals and audio recordings of workshop discussions; videos recordings and transcripts of lessons; as well as audio recordings and transcripts of post lesson discussions on scientific discourse (teacher questioning and student thinking). I analysed these different data to find evidence of teachers' learning and collaboration, focusing on teachers' reflective comments at workshops and post lesson discussions as well as their enactment of practices in lesson conduct. The use of different evidence of learning from workshops journals, observations and post lesson discussions not

only ensured "credibility" / "internal validity" by triangulating different data sources of information (Creswell, 2009); but also allowed me to analyse and map the process of learning (change sequences, growth networks) for each teacher using the model of Clarke and Hollingsworth (2002). It should be noted, however, that the purpose of this study was not to generalise the observations of the four teachers to teachers in other classrooms. The aim was to understand how each teacher initiated changes and grew over time as well as draw patterns across the change sequences and growth networks across the multiple case studies of teachers G, J, A and Y. These insights on teachers' process of learning were useful in informing the design of professional development that can be implemented within the teachers' school context and incorporated into teachers' continual learning.

In view of the purpose of the study, the unit of analysis was the teacher, that is, how each teacher showed evidence of learning and collaboration as the professional development was initiated. I analysed the evidence of teachers' learning; enacting and reflecting on questioning across the following learning experiences:

- At the start of the days one and two workshop
- After the introduction of Chin's (2007) questioning framework at the workshop
- Planning, conducting and reflecting on the first pair of lessons on heat transfer (Primary Four Teachers G and J) and plant reproduction (Primary Five Teachers A and Y)
- Planning, conducting and reflecting on the second pair of lessons on heat conduction (Primary Four Teachers G and J) and plant dispersal (Primary Five Teachers A and Y)
- At the day three workshop
- Planning, conducting and reflecting on the third pair of lessons on light and transparency (Primary Four Teachers G and J) and plant transport (Primary Five Teachers A and Y)

- Planning, conducting and reflecting on the fourth pair of lessons on light and shadow (Primary Four Teachers G and J) and plant processes (Primary Five Teachers A and Y)

The aim of the analysis was to interpret teachers' process of learning. Using evidence of teachers' learning, the change sequences or growth network for each of the four teachers were mapped over the period of six months. The analysis process is described below:

1.   Identify evidence of teachers' learning through how teachers enacted and reflected on Chin's (2007) framework (Appendix A) of questioning approaches (Socratic questioning, verbal jigsaw, semantic tapestry or framing) - their knowledge, belief and practice to promote high cognitive levels (based on Revised Bloom's Taxonomy) of student responses within the teacher-student scientific discourse in different contexts of inquiry activities. The evidence of teachers' learning in the following data sources are coded as described below.

- *Workshop journal entries as well as audio recordings and transcripts of workshop discussions.* Evidence of learning from individual workshop journals and discussions with other teachers are coded "WJ" and "WD" respectively.

- *Audio recordings and transcripts of post lesson discussions.* Evidence of learning from the post lesson individual comments and discussion with other teachers are coded "PC" and "PD" respectively.

2.   Analyse evidence of each teacher's learning for change sequences and growth networks across lessons using the interconnected model of teacher professional growth (Clarke and Hollingsworth, 2002; Clarke and Peter, 1993; Teacher Professional Growth Consortium, 1994) in the following four domains:
- Personal domain (knowledge and beliefs)
- Domain of practice (professional experimentation)
- Domain of consequence (salient outcomes)
- External domain (source of information or stimulus)

The above analytical process helped to first identify teachers' evidence of learning in questioning, which facilitated subsequent analysis of their change sequences and growth networks. The data on teachers' evidence of learning across the various learning experiences, from the "days one and two workshop" to the "planning, conducting and reflection of lessons" (from page 34) will first be presented as narratives of teachers' learning journeys of questioning in Chapter 4 (Section 4.1). In these narratives, the evidence of learning of all four teachers G, J, A and Y individually and with other teachers will be presented concurrently, which can include teachers' enactment and / or reflection of questioning.

The presentation of narratives of the four teachers' learning journeys facilitated the subsequent analysis and presentation of how each teacher showed evidence of learning and collaboration in Chapter 4 (Section 4.2). Each teacher's learning journey will comprise his or her own illustration of enactment and reflection of questioning, followed by the change sequences and growth networks identified based on teachers' evidence of learning across learning experiences. These individual case studies will be further compared to understand patterns in teachers' enactment and reflection; as well as their changes and growth in questioning. These findings will provide insights into how teachers learn and collaborate in questioning to promote higher order scientific discourse in primary science in the real-life contexts of the school / classrooms.

As I was involved in both collecting, interpreting and presenting data, I needed to be cautious of researcher bias (Creswell, 2009). Besides using different evidence of learning from workshops journals, lesson observations and post lesson discussions across learning experiences, I minimised the threat to interpretive validity by supporting my interpretations with evidence of learning using low-level descriptors in reporting, following closely to teachers' reflections in Chapter 4.

3.4 Political and ethical issues

Next, I discuss the political and ethical issues in the design, conduct, dissemination and use of the research.

Considerations in designing research. In designing this study, I had to consider the selection of schools and teachers. *Political considerations* were implicated as I had to make a choice among 178 primary schools as the Principal might question why the school was chosen. After deciding on a nearby school which was representative of a typical government / public school, I sought the consent of the Principal to carry out my research and communicated why the school was chosen. In terms of *ethical considerations*, I shared the intent of my research in studying questioning in the primary science classrooms and how the findings could be potentially used in the design of professional development and resources. Both the school and the four teachers who participated in the study were informed and willing parties. I also addressed the school's and teachers' expectations of "what was in it for them". Besides conducting workshop sessions and partnering with teachers in post-lesson reflection, I also shared the lesson videos and transcripts with them to facilitate their reflection of scientific discourse (teacher questioning and student thinking). Hence, teachers experienced professional development in the process of being involved in the research.

Considerations in conducting research. A *political implication* of this study is the teachers' perception of my role as an assessor. Prior to observing teachers, I assured them that the lesson observation was non-evaluative in nature and was not meant to be used for teachers' performance report. My participation in the lesson was to support the teachers in using questions to support student learning. I also established the same understanding with the school management. In terms of *ethical considerations*, the research lessons did not serve the dual purpose of lesson observations by the school management. The school leaders did not use these research lessons for the performance reporting for the four teachers.

Considerations in disseminating and using research. In disseminating or reporting teacher questioning practices in each case study, the key *ethical consideration* was the need to maintain confidentiality of the school, teachers and students involved by not stating the actual names of schools, teachers and students in reporting my study. The findings can inform the design of professional development and resources for the next syllabus review and implementation.

In summary, the theoretical framework underlying this study is social constructivism. A case study approach was used to explore how four teachers learn to question to promote higher order scientific discourse for topics on "heat transfer and conduction", "light - transparency and shadow formation", "plant reproduction, transport and processes" in the social context of the classrooms. Workshop discussions, lesson observations and post lesson discussions with teachers were analysed interpretatively. Both political and ethical considerations were considered in the design, conduct, dissemination and use of the study.

Chapter 4

Results

In this chapter, I describe teachers' learning journeys (section 4.1) using evidence of teachers' enactment and reflection on questioning across various learning experiences (from the workshop participation to lesson conduct and post lesson discussion) before presenting the case study of each teacher and mapping each teacher's change sequences and growth network (section 4.2). Finally, comparisons of teachers' change and growth are presented and discussed (section 4.3).

4.1 Teachers' learning journeys

In view of the purpose of the study in exploring how teachers learn and collaborate in using questioning to promote higher order scientific discourse, I will present the analysis of teachers' learning using evidence of teachers' reflection and enactment on questioning across the learning experiences listed earlier on page 34.

4.1.1 At the start of the days one and two workshop

The workshop activities have provided stimuli for Teachers G, J, A and Y to reflect on their prior knowledge and belief on questioning. Evidence of teachers' reflection on their knowledge and beliefs was found in their individual workshop journal (WJ) and discussion with other teachers (WD) during the workshop.

At the start of the workshop, guided by a "KWL" template (what I know, what I want to know and what I learn), the teachers reflected on what they already knew and what they wanted to know about questioning in science classrooms. Teacher A's

reflection that "questioning develops students' thinking and facilitates students' learning" was common among all four teachers – all four teachers knew that questioning can help students to think and learn. Besides reflecting on the role of questioning in student thinking and learning, Teacher G also highlighted that the structuring of questioning can influence students' level of thinking in scientific discourse:

> *"Questioning helps pupils to think ... structuring questions (open or closed questions) can help in the level of thinking." (WJ)*

Both Teachers J and Y also pointed out that questioning can elicit understanding and misconceptions. In addition, Teacher J shared that questions prepare students for learning:

> *"Questions getting pupils to think along certain direction / area to prepare them for learning and to prompt deeper thinking and let pupils reveal their misconception or level of understanding of topics."(WJ)*

Among the four teachers, Teacher Y was the only one who explicitly related questioning to the inquiry process:

> *"Questioning guides the process of inquiry; may elicit misconceptions or lead students in changing prior conceptions; as well as allow students to think more deeply or engage in higher order thinking." (WJ)*

The above teachers' reflections are evidence of teachers' common as well as variation in knowledge about the role of questioning. While teachers shared some similar reflections on the role of questioning in eliciting student thinking and learning, the teachers' reflection also revealed differing interests in learning different aspects of questioning. Both Teachers G and Y were more interested in the "how" of questioning while Teachers A and J were keen to learn the "what" of questioning. The teachers' different interests also reflected teachers' different learning needs. For instance, Teacher G wanted to know how to strategise and ask questions to enhance student thinking, understanding, learning and engagement:

"how to strategise my questions so as to get my pupils to think deeply; questions that are able to show that pupils are able to understand concept; how to ask the appropriate questions to enhance pupils' learning and to keep pupils engaged and challenged." (WJ)

On the other hand, Teacher J wanted to know the types of questions to ask for different purposes:

"Do we use certain types of questions for certain topics or for certain stages and what types of questions prompt higher order thinking?" (WJ)

Further evidence of teachers' reflection on their knowledge on question types was found in teachers' other entries in their journals prior to the introduction of Chin's (2007) questioning framework. All four teachers highlighted the "what", "why" and "how" question types but demonstrated their knowledge in different ways. For instance, Teacher G cited specific examples of "what" questions (e.g. "What is heat?", "What are the similarities and differences?") and "why" questions (e.g. "Why is the range of clinical thermometer from 36 to 45 degree Celsius?"). He elaborated that the "why" questions can get students to think deeper and make connections. In particular, he highlighted to the workshop participants how the question "Why is the range of clinical thermometer from 36 to 45 degree Celsius?" can help students make connection that the body temperature is within this range of temperature.

Like Teacher G, Teacher Y cited specific examples based on the topic "reproduction" that she was then teaching. In addition, Teacher Y also stated the purpose of questions (in parenthesis):

"Why is there a need for reproduction in the natural world? (to draw out big ideas in the topic of reproduction); How is a family tree different from a classification table? (to make cross comparisons between what they have learned previously); Can a child look exactly like his or her parent? (to elicit misconceptions)."(WJ)

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Compared to Teachers G and Y who used specific questions to illustrate question types, Teacher A used question prompts instead and stated their purposes (in parenthesis):

> *"Why ... (check if students know rationale); How will you ... (procedural); What if ... (scenario-based/prediction); If ... (scenario-based/prediction); What do you think ... (prediction/justification); What can you suggest ... (alternative solution/proposal); How can you design ... (creative problem solving); Which do you think ... (evaluating)." (WJ)*

The above evidence shows teachers reflecting on questioning in both specific and generic contexts, considering purposes and topics in some instances.

Besides reflecting on their knowledge on questioning, teachers also reflected on their beliefs on questioning. All four teachers believed in using questions to scaffold students' thinking, as evident in their journal entries at the start of the workshop. The reflections on thinking included not just the level of thinking (Teacher G), the scaffolding of thinking (Teacher J), the depth of thinking (Teacher A) but also thinking about own's thinking (Teacher Y). In addition, Teachers J, A and Y also believed in getting students to ask questions. These reflections are evidence of teachers' belief in responsive questioning during scientific discourse for student thinking.

The evidence of teachers' individual knowledge and belief on questioning was generally consistent with evidence of their discussions with other teachers on the first video of a teacher-directed lesson on energy screened at the workshop. Teachers' observations and analysis of this video lesson and subsequent video lessons are useful in better understanding their knowledge and belief of questioning in the various contexts of inquiry activities. Teachers J, A and Y continued to focus on discussing the role of questioning in scaffolding thinking and noticed the use of "recall questions" which promoted "memorising and recalling" when analysing the video. Teacher G went beyond the role of questioning and highlighted to the group participants the importance of pedagogy in promoting student-centred lessons and student outcomes:

"It comes back to pedagogy. It clearly shows that the teacher does not have any strategies. We are in the digital world and there are so many options for us. He rather wants to highlight and use the textbook. It wasn't student-centered. I don't know what are the student outcomes he is looking for. Generally, I think the lesson is not a structured lesson." (WD)

4.1.2 After the introduction of Chin's (2007) questioning framework at the workshop

At the next part of the workshop, each of the four teachers chose to read a questioning approach of his or her choice from the Chin's (2007) questioning framework before sharing what they had learned with the other teachers. For instance, Teacher G chose to read more about the "verbal jigsaw" questioning approach and highlighted what he learned in his own words to the other workshop participants:

"This type of questioning is basically used in lessons where there are a lot of emphasis on scientific terminologies and scientific vocabulary. Used for descriptive information mainly. It can be used for pupils who are weak in their language. Weak in expressing. Weak in stating what they know. Questioning technique emphasises on technical terminology." (WD)

In fact, prior to the introduction of Chin's (2007) framework, Teacher G already observed the features of this questioning approach "verbal jigsaw" in one of the first video analysis although he did not use the specific terminology:

"Interestingly, she managed to elicit responses without asking a question. More like completing a sentence. Because there was role play and then she said ... pupils were all ... and then ... got the students to answer ... completing. So, there wasn't a direct question. Just eliciting the response. Completing a sentence by getting the responses from the pupils. That is one interesting thing without the question."(WD)

Based on Teacher G's reflections above, both Chin's (2007) questioning framework and the video lessons were useful external stimuli for observing and describing features of questioning.

Unlike Teacher G, Teacher Y chose to read more about the "semantic tapestry" questioning approach and pointed out that it can elicit thinking from different perspectives:

> *"The teacher gives questions that can elicit student thinking from different perspectives. They will have to look at multiple aspects of a problem, instead of just one aspect. For focusing and zooming, the teacher uses a questioning lens which enables her to focus on the question in a broad perspective and zoom in on a very focused area of a problem. Just like zooming in and out using questioning skills."(WD)*

For Teachers A and J, besides reading and sharing their understanding of another questioning approach "Socratic questioning" that they chose to focus on, Teacher A highlighted two observations on how the teacher restated students' responses before posing a question from the example provided in Chin's (2007) paper. Teacher A's observations prompted a question from Teacher Y on whether the "pumping" strategy of the questioning approach "Socratic questioning" could guide students to deeper level of thinking. Teacher Y's clarification led to Teacher J providing her own perspective that "pumping" can be used to "pump" for not only depth but breadth of concepts. Hence, the examples in Chin's (2007) paper were stimuli for discussion on specific questioning approaches:

> *Teacher A:* *Pumping is basically when you like to request for more information from the students. In this example, the teacher specifically requested for more examples. The two things I noted is that the teacher will restate what the students have first mentioned and then pose a question to lead them to the next step, relevant to the question that is posed.*
>
> *Teacher Y:* *Sometimes, Socratic questioning is defined as very high level form of questioning that enables Socratic thinking ... Socrates. How is the scaffolding, the usual pumping in class in guiding students to think deeper ... really lead to deeper thinking?*
>
> *Teacher J:* *Pumping may not be depth. It may be breadth ... more examples. It might be deeper sometimes. (WD)*

After the introduction of Chin's (2007) framework of questioning approaches at the workshop, all four teachers were found to analyse the video lessons and

engage in discussion of questioning approaches using specific terminologies. For example, Teacher G did not make comments during the first group analysis of the video lesson featuring a whole class discussion of "fruit dispersal by animals". However, during the second analysis of the same video lesson after the introduction of Chin's (2007) framework of questioning approaches, he engaged in a discussion of possible questioning approaches and their features with Teacher J. He was also able to use the names of the questioning approaches such as "multimodal" and describe features of questioning such as "word association". Being able to name and describe features of the Chin's (2007) questioning approaches is an evidence of learning:

> Teacher G: Can it be sensory if it is imaging?
> Teacher J: Can imagine right ... can still remember... using other senses too.
> Teacher G: Multimodal.
> Teacher J: There is pumping also ... examples of fruits.
> Teacher G: Association of words.
> Teacher J: Verbal jigsaw. (WD)

Unlike Teacher G who did not comment during the first group analysis, Teacher J commented but only described the broad purposes of questions during the first group analysis of the video lesson featuring a whole class discussion of "the variables in a plant investigation":

> "Think the questions also arouse interest, got the children to focus on "soil" and get them to think." (WD)

However, during the second analysis of the same video lesson after the introduction of Chin's (2007) framework of questioning approaches, Teacher J used the names of the questioning approaches such as "verbal jigsaw" and gave examples using specific segments from the teacher-student scientific discourse. Being able to cite specific examples of Chin's (2007) questioning approaches from the video stimulus is another evidence of learning:

> "Mrs S used verbal cloze. She says "same amount of ... the children say "soil." (WD)

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Unlike Teachers G and J, Teacher A did not focus as much on analysing the questioning approaches used in the video case lessons but questioned the differences between them. He questioned the difference between Socratic questioning (pumping) and semantic tapestry (focusing and zooming) when another workshop participant suggested that the questioning approach of semantic tapestry (focusing and zooming), rather than Socratic questioning (pumping), was used in one of the video lessons. He suggested that there might be overlap between the two questioning approaches. Engaging in comparing Chin's (2007) questioning approaches is yet another evidence of learning:

> *"When you ask the "why"questions, isn't it pumping? Asking additional information, just that it is deeper. You start with dispersal ... you talk about fibrous husk ... then you go back to disperse ... then go to examples ... so, isn't that pumping? As much as it is zooming in and zooming out? It seems that there is some overlapping parts of it. But, it is not completely similar, you know what I mean?... It is a natural course of questioning." (WD)*

The evidence of teachers' individual reflection and discussion with each other on Chin's (2007) questioning framework has illustrated how teachers learned individually and with others on using literature and examples of teaching and learning as stimuli.

4.1.3 Planning, conducting and reflecting on the first pair of lessons

4.1.3.1 Planning, conducting and reflecting on the first pair of lessons on heat transfer (Primary Four Teachers G and J)

Right from the group analysis and discussion of a heredity video lesson presented at the workshop after the introduction of Chin's (2007) questioning framework, Teacher G identified the "framing" questioning approach while

Teacher J clarified on the differences between the two subcategories of the "framing" questioning approach:

> *Teacher G:*   *Procedure ... step by step ... question based ...*
> *Teacher J:*   *What is the difference between prelude and outline? (WD)*

During lesson planning at the workshop, Teachers G and J decided to use the "framing" questioning approach in planning and conducting the "heat transfer" lesson. Teacher G explained their choice on using "framing" as the experiment in the lesson was procedural in nature, like what he pointed out at the workshop. Teacher J affirmed their common objective of framing students' thinking on heat flow and gain during the post lesson discussion:

> *"(Teacher) G and I started off thinking that it is good to start the framing part because we want them to be in the mode of heat flow. That's why we have discussed these questions to frame their thoughts." (PC)*

When planning for the lesson, Teachers G and J used the lesson plan template suggested at the workshop to identify the curriculum outcomes, phases of lesson development, as well as the key inquiry question(s) and questioning approach in Appendix J (Table J-1). They also planned sub-questions for each key inquiry question.

When reflecting on the use of the "framing" questioning approach, Teacher G shared that the desired student outcomes of the lesson guided him in planning the questioning approach for both phases of the lesson – the experimental phase and the real life situation phase:

> *The experimental phase:*
> *"For me, I want them to notice ... demonstrate such an aim that heat travels from this to this ... what kind of experiment ... what kind of materials do you use and why are we doing these processes. It is more of, if you were asked to demonstrate it, what are the procedures. And, looking at what is going to happen in the experiment and also the steps." (PC)*

The real life situation phase:
"It is the connection to the concept that they learn in the experiment, that heat flows in real life situation. Gave them the situations and asked them questions leading to elicit the fact that there are certain things that gained heat and certain things that lost heat and this affects temperature. The questions were basically to elicit the concept from them, from the real situation." (PC)

Besides the use of the "framing" questioning approach, Teacher J also reflected on the need to include other questioning approaches such as "Socratic questioning (reflective toss)" as the lesson progressed to respond to her students' thinking. This reflection resonates with her earlier belief at the workshop about scaffolding students' to "think along certain directions":

"But as the lesson progresses, have to think how to direct them to the right path when they are not there and I think for my class, the children were thinking quite fast. They actually tossed me a few questions. I tossed it back to them. So, that was the reflective toss." (PC)

For instance, Teacher J highlighted a part of the lesson where her students had to propose a way to identify a coin, amongst a few coins, which was previously held by a student in a given scenario. She reflected on how she used the "reflective toss" and "constructive challenge" strategies of the Socratic questioning approach to facilitate the class discussion of students' proposals:

"They actually track me off my lesson and I was so late. But I did not want to let it go because it was really very challenging and the children ... this class is able to think. It was reflective toss first of all. The other is constructive challenge. Because I did not give them the answer. I wanted them to answer for themselves. It was quite good I thought because they gave me a few examples." (PC)

Like Teacher J, Teacher G also highlighted the use of Socratic questioning (constructive challenge) and even cited students' work as evidence of how Socratic questioning (constructive challenge) has helped in promoting student thinking and understanding. In fact, Teacher G has indicated at the start of the questioning

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workshop that he wanted to know how to strategise and ask questions to enhance student thinking and understanding:

> *"The questions were geared more for them to think through and answer. So, it is a thinking phase in relation to the real life situation. This happens ... temperature decreases ... step by step. For them to see the concept ... gain and then increase in temperature. So, it was broken down into stages. Finally, I thought they got the concept. In the worksheet, when I looked around, they finally understood. That was evidence that questioning is helpful."* (PC)

The reflections of Teachers J and G prompted further discussion and comparison on the scenarios that each of them posed in their respective classes to encourage higher-order scientific discourse. They discussed students' thinking and Teacher G suggested that the scenario that was posed to Teacher J's students might have provided opportunities to exhibit higher level of student thinking:

> *Teacher J:*   *I thought they were able to analyse because they need to ... analyse the problem and come out with the solution. The evaluating part was more or less done by me, suggested by me because I told them actually what will happen after that ... will your method work or not. And then, I got them to think about it.*
>
> *Teacher G:*   *What I can see is because we use different challenges ... the coin challenge which is not a common one. Something that requires a lot of thinking. Mine is simple ... heat travels. Everyday's life experience. So, your challenging question was very important. I mean the scenario was very important for such questions to come out from the children and for you to ... what challenge you throw at them is very important. Mine is a very simple challenge. That is my opinion.* (PD)

While discussing the design of scenarios to promote higher-order scientific discourse, Teacher J also shared how both of them changed one of the scenarios after receiving feedback at a science committee meeting. Instead of placing a heat source at the end of a metal rod with thumbtacks attached at regular intervals (a typical scenario which students would be more familiar with), they took up a committee member's suggestion to shift the heat source to the middle of the rod with thumbtacks placed at

either side of the heat source to check for students' understanding of heat flow. This is evidence of teachers learning from different platforms, beyond the planned workshop, their own lessons and post lesson discussions:

> "We prepared and we had a science committee meeting and giving feedback. How can we make it interesting? That particular one ... let's move it to the middle and see if the students can understand." (PC)

At the end of the post lesson discussion, both teachers reflected on what they did differently in these two lessons from previous lessons and what they could have done differently in the current lessons. These reflections indicate changes in practice / belief of questioning. For instance, Teacher J reflected on what she had done differently from her Primary Four lessons the previous year. She said that she has learned and adapted the questioning approach "semantic tapestry" cum role play pedagogy from one of the videos of teaching and learning at the questioning workshop. She wanted to address students' difficulties in relating to objects gaining / losing heat and prepare them for examination tasks. This prompted Teacher G's reflection on why he did not use "semantic tapestry (multi-modal thinking)" and how he could also make use of this questioning approach to enrich his lesson. This is an evidence of Teacher G learning from the discussion with other teachers and how the post lesson discussion reinforced learning of a questioning approach first introduced at the workshop:

> Teacher J: I did the semantic tapestry. I find children always have a problem talking about ice melting and temperature. They always think that ice loses heat. I learned from Mrs S's case study. She is the Sun. I got that idea and that's why I asked them to imagine that they are ice. I was teaching last year, same level but did not use that strategy. So, I learned that it was possible and I am able to use "if you were ice". Last year, this is an area where a lot of children have problem in trying to relate what object gained heat. A lot of the questions test students on what objects gain heat ... lose heat ... exam testing.
>
> Teacher G: Previously, I was not aware of multi-modal. I won't think about it. Now, I think I can put that in. That will help enrich my lesson. Like what she said, the thinking process is much better. Definitely, the lesson improvement, for me is there.

After the discussion, I ask myself why I did not use multi-modal. Very good strategy to use. I am learning. Probably, next lesson, I try to do that. (PD)

Besides reflecting on what she has learned and applied in her lesson, Teacher J also reflected on the importance of how a question is posed in scaffolding students' thinking. This is evidence of Teacher J starting to value not just the "what of questioning" that she was interested in knowing at the start of the workshops but the "how of questioning" too:

> *"I see the value of constructive challenge ... stimulate their thinking. In order to challenge them, how I pose a question is very important. So, I see that how I asked the question and sometimes to scaffold step by step to guide their thinking. I find that they actually know how to think and create solutions." (PC)*

When reflecting on the overall use of questions in this lesson, Teacher G himself identified changes in his questioning practice from previous lessons. He highlighted his awareness of questions that he previously was not, as well as thinking of questions prior to the conduct of lessons:

> *"Generally, the thinking through before the lesson, what kind of questions to ask. There is a lot of thinking as to how ... what are the main questions. In fact, during the lesson, I was trying to stick to these questions. The advantage was I already kind of thought through and I know what to ask. Secondly, I am also now aware that I can use other forms that I have not used before e.g. multi-pronged and use situations." (PC)*

In this post lesson discussion of the first pair of lessons, Teachers G and J reflected on how to use questions to further develop students' higher order thinking in scientific discourse. They have also started to reflect on changes in their own questioning practices.

4.1.3.2 Planning, conducting and reflecting on the first pair of lessons on plant reproduction (Primary Five Teachers A and Y)

When learning about Socratic questioning during the workshop with other teachers, Teacher A highlighted how the teacher restated students' responses before posing a question based on the example provided in Chin's (2007) paper. Teacher A's comments prompted a clarification from Teacher Y on whether the "pumping" strategy of the questioning approach "Socratic questioning" could guide students to deeper level of thinking. This is evidence of teachers reflecting on the structure of Socratic questioning as well as how it can be used to promote student thinking:

> *Teacher A:* *Pumping is basically when you like to request for more information from the students. In this example, the teacher specifically requested for more examples. The two things I noted is that the teacher will restate what the students have first mentioned and then pose a question to lead them to the next step, relevant to the question that is posed.*
>
> *Teacher Y:* *Sometimes, Socratic questioning is defined as very high level form of questioning that enables Socratic thinking ... Socrates. How is the scaffolding, the usual pumping in class in guiding students to think deeper ... really lead to deeper thinking. (WD)*

During lesson planning, Teachers A and Y decided to focus on Socratic questioning. Unlike Teachers G and J, they did not use the lesson plan template suggested at the workshop. They decided to use the school's lesson planning template in Appendix J (Table J-2). This is evidence of how teachers may apply and combine what they have learned with existing school practice.

When reflecting on the use of Socratic questioning in their lessons on plant reproduction, Teacher A shared that he wanted to help students visualise the plant reproduction process through role play and his questions served to ask students about the processes:

> *"For my group of students, it is more to help them be able to visualise how to role play and act it out that particular process. My students need to*

work with each other, warm up and they also have difficulty trying to come out with ideas. So, the questioning is more to ask the process." (PC)

Teacher A elaborated on students' difficulty in making the link between what they understand and how to demonstrate their understanding. Hence, he highlighted the need to facilitate by asking questions such as "How are you going to show?" while students were planning their role play. This is evidence of Teacher A reflecting not solely on the questioning approach but how the role play together with questioning can support student visualisation in the learning process:

> *"The linking between what they understand and how to demonstrate it so that others in the class can understand. They were a bit slow in coming out with their ideas. This is more to facilitate that." (PC)*

Besides facilitating students' understanding and demonstration of the processes of plant reproduction through role-play and questioning, Teacher Y also highlighted the need to find out if her higher ability students, who usually had more prior knowledge, had any misconceptions:

> *"I just wanted to see what they already knew. Based on the ability of this class, they tend to read up more than what is given. Just wanted to see if they had any misconception." (PC)*

One of the students' misconceptions that Teacher Y noticed was that of pollination and fertilisation. When asked to explain what pollination is, students said "fertilisation". She reflected that she used the strategy of "constructive challenge" of Socratic questioning to encourage students to explain pollination and fertilisation without telling them what these terms meant. She continued to use Socratic questioning to check for students' understanding of other terms such as "nectar" and "pollen" in the later part of the lesson, making specific reference to a question in her lesson transcript:

> *"I wanted to ask a question at the bottom of page eight (lesson transcript) to see if they were still confused about the two and to refer back to the start of the lesson as well. Because they were a bit confused between the two processes pollination and fertilisation." (PC)*

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Besides discussing students' understanding and misconceptions, Teachers A and Y further discussed students' thinking during scientific discourse at both the planning of role play and role-playing itself. Teacher A commented that the questions posed to students while they were planning for the role play were different from questions asked while facilitating their role play as the purpose of questioning was different. This is evidence of Teacher A reflecting and comparing questions used in different parts of his lessons:

> *"Because this one is during demonstration. So, it is different. I mean initially the how question is to help them connect between what they understand and how they show. When they present it, it is connecting back ... is to ask them ... now you show this already ... this that you have shown, what does it show. So, it is going backwards. But then, from linking back, we go deeper." (PC)*

He further identified examples of questions he posed during students' role play presentation, such as "How does the husk help the coconut to float?".

Overall, while both teachers agreed that students were provided the opportunity for higher order thinking such as applying and creating in their lessons, Teachers J and A had a discussion on whether the platform rather than the questioning facilitated students' higher order thinking and the student thinking involved:

> *Teacher J:*   *I thought that it is more to applying ... because we gave them the information. They just have to try to represent it ... creative in that sense ... I thought it is more of the platform, rather than the questioning.*
> *Teacher A:*   *I think the platform gives room for higher order, like creating. The nature of the activity is already about creating something. It gives room for evaluating their own thinking".* *(PD)*

Teacher A's reflection is similar to Teacher G's reflection during his post lesson discussion with Teacher J on their heat transfer lessons - that the scenario posed to students could have facilitated students' thinking. These reflections show that teachers are cognizant of other lesson factors that can influence students' thinking in scientific discourse.

In this post lesson discussion, Teachers A and Y focused on discussing questioning approaches and student thinking in stretches of scientific discourse but did not reflect on changes in their practices like what Teachers G and J did in their post lesson discussion.

Comparing the evidence of learning presented so far through the four teachers' enactment and reflection on these first two pairs of Primary Four and Primary Five lessons, all four teachers enacted their chosen questioning approaches (Framing for Primary Four, Socratic questioning for Primary Five) in their respective lessons. Besides, Teachers G and J had started reflecting on changes in their practice and how they could change their practices to promote higher level of student thinking in scientific discourse in various contexts of heat transfer. On the other hand, Teachers A and Y reflected mainly on how the questions were used in different parts of their lessons to promote student understanding and misconceptions of plant reproduction.

4.1.4 Planning, conducting and reflecting on the second pair of lessons

4.1.4.1 Planning, conducting and reflecting on the second pair of lessons on heat conduction (Primary Four Teachers G and J)

While planning and conducting these next two lessons on heat conduction, different external stimuli (e.g. different lesson contexts; different discussion points between Teacher G and Teacher J) as well as different practices (e.g. specific questions used) prompted different reflections. This second pair of lessons has provided Teachers G and J with opportunities to enact and reflect on questioning in different ways within the same "heat" topic.

For this second pair of lessons on heat conduction, Teachers G and J also used the "framing" questioning approach in planning and conducting the lesson. When

planning for the lesson, like the first lesson, they also identified the curriculum outcomes, phases of lesson development, as well as the key inquiry question(s) and questioning approaches in Appendix J (Table J-3). They continued to use the lesson plan template suggested at the workshop and planned sub-questions for each key inquiry question.

During the post lesson discussion on how the "framing" questioning approach was used to scaffold students in using the datalogger heat sensor to measure the temperature of water in three different cups made of different materials (ceramics, metal, styrofoam), Teachers G and J compared the difference between framing (prelude) and framing (outline). In fact, Teacher J first clarified on the framing questioning approach at the workshop itself and showed evidence of deeper understanding of the strategies within the framing questioning approach in the context of this lesson:

Teacher G:	*It is the first time we were using datalogger. So, it is procedure on how...*
Teacher J:	*You give them instruction first, then they do or? Mine was instruction first as they do. The next instruction, then they do.*
Teacher G:	*Correct ... similar ... I told them ... move to this ... click this ...*
Teacher J:	*But they never put the heat sensor into the water first? So, that is the difference.*
Teacher G:	*Yours ... they put the sensor in already?*
Teacher J:	*Yes. Put the heat sensor inside then turn on the datalogger. While doing ... what do you call that? Giving step by step instructions while they are doing the experiment?*
Teacher G:	*Mine would be prelude.*
Teacher J:	*Mine is more of outline.*
Teacher G:	*Actually, now that you categorise it, I find that difference ... ideally, if I was given an option, I will go through the procedures in a separate lesson. How to use it. Here, I am putting in the concept, putting in the procedure, it may confuse the children. In that class, some were not able to do it. Then, I have to go to attend to them. That is a lot of disruption to the lesson. (PD)*

Besides reflecting on the different strategies of the "framing" questioning approach, Teacher J shared that she liked the use of the "framing" questioning approach as an advance organiser to help students make connection to the past experiment on heat transfer:

> *"We actually planned the questions before and, the question-based framing. Start as an advance organiser to frame the lesson for the children. When I look at it, I kind of like it because I was able to bring their minds about the flow of heat to the different materials / objects using the rod as an example, referring to the past experiment." (PC)*

Besides reaffirming the value of the "framing" questioning approach based on practice, Teacher J added that the use of Socratic questioning (reflective toss) alongside framing facilitated students to think further about heat conduction:

> *"When I asked them about wood ... what if I used wood ... I think a lot of them were saying like ... page two (of transcript) ... they had the idea that the fire is directly burning the wood and the wood will definitely burn which is not wrong. Then, I have to think and try to tell them that fire is not touching the wood. They said no and I tossed it back to them ... how about this situation. Think again. " (PC)*

Teacher J's reflection is consistent with her reflection at the post lesson discussion of the first pair of lessons about the value of using a mixture of questioning approaches of framing and Socratic questioning.

Besides reflecting on the "framing" questioning approach which was pre-planned, Teacher J also highlighted a problem which cropped up during the lesson and how she had to "think on her feet" to question to support students in discussing their unexpectedly low datalogger reading. This prompted a discussion between herself and Teacher G on how the strategies of Socratic questioning (constructive challenge or reflective toss) were used in this stretch of teacher-student scientific discourse to promote student thinking:

> *Teacher J:*   *It just click on me. I walked around and saw their figures and mine. I asked that question. It was an impromptu kind of thing. I am dealing with students in this class. I want*

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	them to be very aware of things around them. So, I went back and asked.
Teacher G:	*So, they came up with the answer? What did they say?*
Teacher J:	*Room temperature because it is in the air.*
Teacher G:	*They concluded that it went down to room temperature. So, this is an opportunity which was not planned but the questions came out spontaneously and it was a good and effective thing. What do you call that? Constructive challenge?*
Teacher J:	*It was a reflective toss. They were telling me that my heat sensor was left longer. So, I posed a question back to them. It can be a constructive challenge as well. I think there is some form of evaluating.*
Teacher G:	*Analysing ... they are reasoning out ... is reasoning a form of analysing?*
Teacher J:	*I thought ... first they make an evaluation ... whether my answer is right or wrong first. Then, if it is right ... if it is wrong, what makes it right or wrong. Then, they think further. Then, they have to analyse the situation – what is actually contributing to the answer. (PD)*

Besides reflecting on the use of questioning approaches, Teacher G continued to reflect on how he could improve his questioning practice for students' higher order thinking in scientific discourse. This was what he also did during the post lesson discussion of the first pair of heat transfer lessons. When analysing the experiment data and concluding on which material (ceramics, metal, styrofoam) was the poorest conductor of heat, the students' data showed that ceramics was the poorest conductor though the students originally predicted that styrofoam was the one. Teacher G reflected that he did not use the opportunity to elicit higher order thinking and suggested a possible question that he could have used to engage students in discussing variables of the experiment:

> *"I should have used the opportunity to say why ceramics was a poorer conductor. Because the variables also come in ... the thickness of the cup. I did not use the opportunity. It is a very good opportunity for higher order thinking. Here, the question would be ... are the cups the same size? Material is different. That is what we want. Size has to be the same. Thickness as well. That would have been good opportunity for them to reflect on their concept of variables." (PC)*

Teacher G also analysed students' responses and reflected on how he could have questioned to encourage higher order thinking in his students when applying the findings of the experiment to everyday life examples (frying pan). For example, besides asking students to analyse what the handle of frying pan was made of and why, he could have asked students to suggest other materials that could also be used to make the handle:

> "Analyse ... may be to a certain extent ... why wood ... why the handle must be bad conductor ... not a very high level of analysing. More application. May be if we had thrown a question "What else could you have used to make the handle? Then, there is some creation." (PC)

Teacher G also reflected that though he has provided a specific everyday context for students to apply their understanding on heat conduction in his lesson, he could have used more open questions to further encourage his students to think how heat affected their lives:

> "Framed. Very contextualised. Wasn't open. But in the questioning, we could have opened it quite a bit. How does heat affect your life?" (PC)

Besides reflecting on questioning to promote student thinking in scientific discourse, Teachers G and J also reflected on the design of the student worksheet. When asked why the worksheet was more guided compared to the focus on higher order thinking during scientific discourse in class, Teacher J highlighted the importance of language use while developing student understanding:

> "We were very concerned about language. You know children are always confused between better ... good conductors of heat. So, we are also quite targeted in that sense. Quite focused. Gear them to understand. (PC)

When reflecting on the overall use of questions in this second pair of lessons compared to the first pair of lessons on heat, Teacher G highlighted that he has learned that he can ask questions to inculcate the value of cooperation in science investigation:

"This case, I am looking at questions which can also bring out values. Now, since you brought out the cooperative learning, the value aspect, there are certain questions where I can think about. I never thought about that in the first lesson. This is one take-away, definitely." (PC)

In fact, he highlighted this same learning point as a significant "questioning moment" that has impacted student learning at the day three questioning workshop. He added that he tried to use questions to encourage cooperation at subsequent lessons. This is evidence of how practice reinforced his belief and encouraged further practice:

"Interesting to find out that I can ask questions that can encourage cooperation in an activity. I tried and true enough there was a lot of support and encouragement. Each group was doing one data ... what did the other group have ... so there was a lot of sharing going on ... and there was a lot of interaction and cooperation". (PC)

Besides reflecting on questioning and student thinking in the scientific discourse, Teacher J highlighted the value of both the video viewing and lesson transcript analysis. This is evidence of Teacher J thinking about what helped her in reflecting on her questioning practice:

"At the end of the two observations, we are more conscious of what questions can do for us. I was more conscious so this time I am not so fierce. Watching the video ... you see the movement, you see the context. You can relate the context and the relevance of the questions. If you look at the text, you can think more deeply. I think each serves different purpose." (PC)

In this post lesson discussion, Teacher G continued to reflect on how he could better use questions to scaffold students' higher order thinking in scientific discourse as well as inculcate value of cooperation in data collection and analysis. On the other hand, Teacher J continued to reflect on how she tapped on opportunities presented during scientific discourse to question to promote students' higher order thinking. She also started thinking about what helped her in reflecting on questioning and student thinking in scientific discourse.

4.1.4.2 Planning, conducting and reflecting on the second pair of lessons on plant dispersal (Primary Five Teachers A and Y)

While planning and conducting the next two lessons on plant dispersal, different external stimuli (e.g. different lesson contexts; different discussion points between Teacher A and Teacher Y) as well as different practices (e.g. specific questions used) prompted different reflections. This second pair of lessons has provided Teachers A and Y with opportunities to enact and reflect on questioning in different ways.

For this second pair of lessons on plant dispersal, Teachers A and Y also used Socratic questioning in conducting the lesson. Like the first lesson, they also did not use the workshop template but used the school's lesson planning template in Appendix J (Table J-4). Unlike the previous lesson, Teachers A and Y also planned sub-questions, in addition to the key questions.

During the post lesson discussion, Teacher A used his video lesson to explain how Socratic questioning was used in the whole class discussion to help students connect between the plant reproduction processes before the hands-on exploration of different fruits. This is evidence of Teacher A using Socratic questioning in a different way from the last lesson:

> *"When I brought up this part, I just wanted them to understand that there are four parts in the process. Any disruption to one of it would impact the whole cycle. At the end, they were giving very practical suggestions or real life suggestions ... meteoroid and all that ... I did not expect such answers actually. So, when it came, I brought them back again to think about ... if there is no seed dispersal, is it possible for the rest to continue. I wanted them to say no ... it is not possible. I wanted them to identify that each of these is equally important in the whole process of reproduction."*
> *(PC)*

Teacher A also used Socratic questioning in facilitating group work and identified key questions that he asked students in different groups from his lesson transcript:

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"I think we are trying to get the students to identify the characteristics of the fruits ... link how these characteristics help in dispersing the fruits. For example, page 13 (of transcript) ... how does the wing-like structure help the fruit? Page 14 (of transcript) ... what makes you think it is dispersed by animals? This is actually asking for characteristics. How do you think they are dispersed? Dispersed by what? Can you tell me one characteristic that tells you it is dispersed by animals? What do you notice about the tomato that tells you it is dispersed by animals?" (PC)

Besides comparing the use of Socratic questioning within the whole class and group work segments of the lesson using his lesson video and transcript, Teacher A also compared the use of Socratic questioning during whole class discussion in this plant dispersal lesson and the earlier plant reproduction lesson to teach the big idea of cycle. He elaborated on the structure of Socratic questioning, alternating between broad idea and details. This is evidence of Teacher A reflecting on his questioning practice across lessons:

"For myself, for both lessons, I started very broad. Very broad view, then zoom in. Similarly for this, zoom straight into some aspects. Then, after that, zoom out. So, for both, that is a similar strategy. We taught cycle then we zoom in focusing on seed dispersal. This is a continuation from last lesson where we also covered cycle then now we zoom in another reproduction process." (PC)

While Teacher Y also reflected on her use of Socratic questioning, but she remained focus on using Socratic questioning to address students' misconceptions. Just like how she reflected on the previous reproduction lesson, Teacher Y reflected on how she used Socratic questioning to address students' misconceptions on "fruits and seeds" as well as "ovum and ovule" that she noticed in an earlier lesson:

"It was more because in the previous lesson, they just used the words seeds and fruits interchangeably. I wanted them to know that the fruit actually houses the seeds. So, sometimes, you need to be observant. Find out exactly where the seed is. Or is it the seed alone that you are seeing. I think it is still more Socratic ... series of questions to guide them towards the goal which is on dispersal. They mix up ovum. We don't teach them ovum. We teach them egg. They mix up ovum with ovule. Because of minor adjustment in spelling." (PC)

When reflecting on her overall approach in using Socratic questioning, Teacher Y first planned question prompts based on students' misconceptions then also used questions to scaffold their understanding. While Teacher A's focus was not on addressing specific misconceptions like Teacher Y, they discussed their common focus on achieving the student outcome of understanding. This is evidence of both teachers' beliefs on using questioning as a means to achieve student outcomes:

> Teacher Y: *I thought, usually for this class, I will start off with asking them a question prompt. And, usually the question prompt is based on some misconceptions I think they might have. Because these children, they read up a lot. Then, they confuse what they read outside with some of the other terminologies. It was more Socratic questioning ... how to guide them in their understanding and to lead them to the learning goal or objective. How does one question link to the next. How these questions can be used to scaffold students' understanding. That was my own personal focus.*
>
> Teacher A: *During the discussion, it is more to see how to bring about that understanding. My focus was not on the questioning or strategy per say. More on how I can question to lead them to ... I am more concerned about depth than thinking about the strategy that I am going to use. I rather think of the outcome. Just ask and lead them to it. In terms of scaffolding." (PD)*

While acknowledging possible challenges when planning for specific questioning approaches, Teacher A suggested tagging certain questioning approaches to certain topics or lessons broadly to facilitate teachers in delivering student outcomes. This is evidence of Teacher A, beginning to value the planning of questioning approaches and also looking beyond his own classroom to explore ways to support other teachers in questioning:

> "May be tagging of certain strategies to certain topics, certain type of lessons ... broadly. If not, with this knowledge or without this knowledge, whether it is as useful as a teacher. How to provide something that is useful for the teacher. When they plan, it is easier for them when they plan. They can focus on certain areas where they know would deliver certain outcomes that is more definitive." (PC)

In the last and current post lesson discussions, Teachers A and Y have held consistent beliefs of using questioning to achieve planned student outcomes and elicit student misconceptions respectively. Teacher A started to reflect across lessons and beyond his own questioning practice to suggest how other teachers can also be supported in questioning.

Comparing the evidence of learning presented so far through the four teachers' enactment and reflection on the first and second pairs of Primary Four / Five lessons, all four teachers continued to enact the same chosen questioning approaches (Framing for the Primary Four teachers; Socratic questioning for the Primary Five teachers) in their respective lessons but for different lesson objectives. Teachers G and J continued to reflect on changes in their practice including the use of other unplanned questioning approaches (Socratic questioning), as well as how they could change their practices to promote higher level of student thinking in scientific discourse. Teacher A also started to reflect beyond his own questioning practice to suggest how other teachers can also be supported in questioning, while Teacher Y continued to reflect mainly on how her questions were used to promote student understanding and misconceptions. Among the four teachers, Teacher J was the only one who started reflecting on the value of using videos and lesson transcripts in reflecting on her questioning practice.

4.1.5   At the day three workshop

At the day three workshop, the teachers reflected on their overall learning experiences on questioning after planning and conducting the four pairs of lessons on heat (Teachers G and J) and plant reproduction (Teachers A and Y). Each teacher reflected on his / her own questioning learning journey using a postcard of his / her choice as a stimulus.

Teacher G used the following postcard depicting a house made of jigsaw pieces to reflect on his own learning and experience in questioning, after planning and conducting the lessons on heat. His reflection is consistent with his enactment and reflections on questioning for the first two pairs of lessons on heat – how he used or could have used different questioning approaches to scaffold students' understanding and higher-order thinking in scientific discourse, building on students' foundational knowledge. This is something that he expressed interest in finding out at the start of the workshop. Besides, his description of the "reflective toss" strategy also showed his belief of students' role in the teacher-student scientific discourse:

"Why I chose this postcard is basically there are different categories of questioning. There can be scaffolding questioning, there can be procedural questioning. We combine so many different types of questioning to form a complete understanding, a complete house. Below this house is actually the foundation. Before children can answer this kind of questions, they need some foundation, some information of the topic. They cannot come in with a blank mind of the topic that we are discussing to answer questions. For

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higher order questions also. The hole is like a reflective toss where you throw back at the children and they have to think how to answer to complete the picture." (WD)

Teacher J used the following postcard depicting a world with different characters to reflect on her own learning and experience in questioning, after planning and conducting the lessons on heat. Her reflections on what she has learned as well as what questions had done for her in different parts of a lesson have addressed her own question at the start of the workshop on whether certain types of questions are used for certain stages of lessons. She also highlighted selected questioning approaches such as "reflective toss" that she liked, similar to what she reflected at a post lesson discussion:

"This reminds me of a typical class. We have a variety of characters and different abilities. I find that questioning is really multi-faceted. I really learn a lot. I find that it can be used to elicit different kinds of responses from children. From the simple one, conceptual, to higher order thinking. So, the range is very wide. And, it can serve different purposes. It can benefit different group of pupils.

What I have learned is that questions can be asked at different parts of the lesson. It can be at the beginning to frame their thoughts ... prepare them for lessons. In the middle, to pump for ideas, prompt them to think and also can be used to stretch pupils' thinking.

The two things I have tried in my lesson is ... I have done reflective toss which I myself enjoy very much. As I listen to the children ... sometimes they ask a question ... challenging question ... I have one answer in my mind ... thinking on my feet. When you toss it back, you find they have some more ideas." (WD)

Teacher A used the following postcard depicting a ballerina to reflect on his own learning and experience in questioning, after planning and conducting the lessons on plant reproduction and plant dispersal. His reflection centered on how to use questions to develop the planned student outcome. This is consistent with his post lesson discussion so far about not just focusing on the types of questioning approaches used but about how he could lead his students to the desired understanding and thinking. He reflected that he had learned about different types of questioning. This heightened awareness in questioning possibilities helped him in planning lessons to support student learning, especially on appreciating big ideas in the theme. This is consistent with his reflections on the use of Socratic questioning to help students appreciate the big idea of cycle theme in the two lessons on plant reproduction and plant dispersal:

"Questioning is an art. When you use it skillfully, you produce a lot of colours in the classroom. Learning will be more interesting, fun and engaging. I have learned about different types of questioning approaches. In the questioning approaches, I also came to realise that actually, we do use them although we are not conscious about it. It is not a matter of doing something new but more raising consciousness and awareness about what we are currently doing. So, we are also able to be more directed in our approach to see how for example we want to develop students in certain areas. At least now, we can immediately attach a certain way of doing to lead them there and we can also observe whether we are moving towards it ... the teaching moment ... the impact on student learning. I think I become more conscious about questions that lead them towards the outcome that I want to achieve at the end of the lesson. So, for example, the learning ... how do I bring them there, what is the best way ... and thinking in line with the whole picture that they have learned before and also the theme. "(WD)

Teacher Y used the following postcard depicting a chocolate bar to reflect on her own learning and experience in questioning, after planning and conducting the lessons on plant reproduction and plant dispersal. She highlighted that what she had learned was to keep the learning outcomes of lessons in mind while questioning. She also reflected that she used mainly Socratic questioning to elicit students' misconceptions and thinking which she also highlighted during both post lesson discussions. She continued to believe in questioning to encourage students' own questions, something that she also highlighted at the first workshop session:

"No need to be so long-winded. Questioning need not be so complex or high level. Can start short and sweet and yet achieve what we want to achieve. Along the way, need to keep the big picture in mind ... the learning outcome of lesson. That is basically, what I have learned. Students can then through these shorter questions, might be able to ask their own questions. Questions to get them to think. As they think, it becomes more apparent to them that there are gaps in their own knowledge. To cover these gaps, they will start to ask questions on their own. For myself, I think I use quite a bit of Socratic questioning. Basically, mostly Socratic questioning ... through which possibly the students can have their misconceptions elicited."(WD)

Based on the evidence of learning presented through the four teachers' enactment and reflection up to the day three workshop session, the four teachers have learned differently and changed to different extents while planning, conducting and reflecting on the four Primary Four (Teachers G and J) and four Primary Five (Teachers A and Y) lessons. The teachers' enactments and reflections have also shown how they have learned from planning and customising lessons as well as reflecting on their practices and discussion points with other teachers. So far, it is observed that the teachers' reflections on their knowledge and belief (personal domain), questioning practices (domain of practice) or student understanding / thinking / misconceptions (domain of consequence) at the day three workshop session were consistent with their reflections at the post lesson discussions.

4.1.6   Planning, conducting and reflecting on the third pair of lessons

4.1.6.1 Planning, conducting and reflecting on the third pair of lessons on light and transparency (Primary Four Teachers G and J)

When planning for the pair of light lessons, like the heat lessons, Teachers G and J also identified the curriculum outcomes, phases of lesson development, as well as the key inquiry question and questioning approaches in Appendix J (Table J-5). They continued to use the lesson plan template suggested at the workshop and planned sub-questions for the key inquiry question.

However, unlike the lessons on heat, Teachers G and J used different and more questioning approaches - "Verbal Jigsaw", "Socratic questioning", and "Framing" for this lesson on "light and transparency" to provide students with more guidance in the learning process. Teacher G explained the need for the chosen questioning approaches:

> *"There was a need. I feel that these questioning approaches are more guided. 1 think they will find light a bit more abstract than heat. That is why I thought they needed more guidance." (PC)*

Besides choosing different questioning approaches, Teacher G also tried small group questioning to increase students' participation / interaction as well as to elicit their thinking. He also highlighted the importance of structuring time to allow students to engage in small group discussion. This is evidence of Teacher G enacting and reflecting on small group questioning that he highlighted at the last post lesson discussion:

> *"The reasoning is I felt that questioning the whole class, the participation rate is much lower ... like it is only one or two children. The rest are a bit inactive. So, what I did was that 1 posed questions to the group. It was similar questions. I went group by group as they were reading. So, there was more interaction and actually my objective of getting more participation in thinking and answering. And, also, I gave them time to*

discuss. There was some wait time to discuss the questions and then I asked them." (PC)

After trying out the group questioning, Teacher G reflected on how students were more forthcoming in responding and how that facilitated him in addressing students' misconceptions:

"I get more people responding. And, any misconceptions, you straight away find out. Because, when you ask as a class, they don't voice out. As a group, misconceptions are evident and you can address it. For example, the question on which sunglasses to use, they were quite a number who said very little light. I said that it is almost opaque. Can you see? I could address that misconception immediately. I think if I did it as a class, it might not have surfaced." (PC)

Teacher J did not focus on small group questioning but continued to reflect on how she tapped on another set of unexpected set of datalogger readings (the amount of light passing through a transparency sheet and tracing paper is the same) to engage students in higher order thinking in scientific discourse.

"I want to achieve my objective of the understanding that different materials allow different amount of light to pass through. Tracing paper has the same reading as transparency sheet. I want them to think whether the datalogger is accurate, whether there is a problem with the reading. I don't want them to just passively receive my answer that it is not all accurate. I want them to always question. I want them to think." (PC)

Teacher J also reflected on how she could have extended her students' thinking further by getting students themselves to evaluate if the datalogger reading was accurate. Her reflection led to Teacher G sharing on how the questioning in small groups also provided opportunities for student thinking such as analysing and evaluating data. He added that the questions that he used in this experiment could serve as a template to be used in other experimental settings. This prompted Teacher J's further comments on how such thinking skills of analysis and drawing conclusion are also expected of students in examinations, relating instruction to assessment:

> Teacher J: *The thing that I regret ... I should have paused and let them evaluate and let them tell me. I feel that I should not have jumped in so fast to say that there is something wrong with the data. It would have been more enriching e.g. if anyone has any comments on this data. I could have done better.*
>
> Teacher G: *Evaluating the readings, definitely. Analysing as well ... pattern going lower and lower ... they were able to say that. In an experimental situation, these are like standard things because that is the objective of the experiment. So, it is like a template. This situation is this kind of questions.*
>
> Teacher J: *For exam questions, if such table does appear, we always need them to analyse and draw conclusions. (PD)*

In this post lesson discussion, Teacher G reflected on another aspect of questioning (small group questioning) while Teacher J continued to focus on reflecting on how she tapped on opportunities presented during scientific discourse and questioned to promote higher order thinking in students.

4.1.6.2 Planning, conducting and reflecting on the third pair of lessons on plant transport (Primary Five Teachers A and Y)

When planning for the plant transport lessons, like the plant reproduction and dispersal lessons, Teachers A and Y continued to use the school's lesson planning template in Appendix J (Table J-6) below. Like the previous lesson, they continued to plan sub-questions, in addition to the key questions.

Just like the first two pairs of lessons, Teachers A and Y used Socratic questioning in the lesson on plant transport. Teacher A highlighted the use of reflective toss, one of the strategies for Socratic questioning:

> *"In general, it is Socratic. I also pose some questions back. So, what do you think it is. I was trying to use a lot of reflective toss actually, as much as I can. They ask a question, I ask them back. I keep throwing back the questions because I want them to be asking more. On the other hand, also for them to think a bit and propose some solutions, rather than I give a solution." (PC)*

Besides Socratic questioning, Teacher Y also used verbal jigsaw to get students to think and inquire like a scientist using scientific terminologies. She emphasised that her lesson objective was based on her belief and interpretation of the curriculum. This is evidence of Teacher Y's belief guiding her questioning practice and her beginning attempt to explore other questioning approaches in Chin's (2007) questioning framework:

> *"To me, I was just trying to get them to see the meaning in conducting experiment. And, relating to what scientists do in the field. And how it is related to real life. I feel that it is very important for students to be able to make that relation to what scientists actually do ... what science is. That is my take on the curriculum ... It is more so like a belief. Something that I think they should take away even if they don't score good grades. But to be able to still have that drive for inquiry. Not just as scientists but also in their own aspects of life. You don't just stop there but think about why certain things happen ... may be use of scientific terminology ... verbal jigsaw ... terms for scientific method." (PC)*

Besides reflecting on their own question use, Teachers A and Y reflected on students' questions and thinking. For instance, Teacher A reflected on how he responded to students' unexpected questions and facilitated the scientific discourse using questions to lead students to the intended goal. He used "revoicing" by repeating students' responses, a strategy also reported by Chin (2007) and introduced at the questioning workshop, so that he had more time to think of his next questioning move. This is evidence of Teacher A valuing questioning to facilitate student questioning:

> *"I have certain questions in mind but I did not expect it to turn out to be so interactive ... The one that surprises me most is ... suddenly, this question popped out. I never thought they would think of that. The challenge is on the spot when they bring up these questions, you don't answer the questions and have to think of how to guide them to the answers. On the spot, you have to respond immediately. That is the challenge. Sometimes, you need time to process a bit. When a child asks a question, you cannot tell him but you want him to be able to go there. Must ask it in a form of a question. There are a few steps to go through then you must straight away question to lead*

them. The first response is ... so you are saying this ... because you need time to think."(PC)

Teacher A elaborated that students were involved in analysing and evaluating as they asked questions and discussed possibilities of set-ups which can give a flower two colours. His elaboration prompted a discussion with Teacher Y on students' thinking and what they could do:

> Teacher A: *I think analysing is quite strong in the lesson and some parts, evaluating. The discourse within the group ... they have to evaluate what their friends say. When the groups presented to everybody, the children are also constantly evaluating. To see if they can themselves defend and discuss. Noticed some groups started to argue and disagree with one another.*
>
> Teacher Y: *(Mine is) more evaluating because they have to devise that procedure and also give the rationale for doing things that they decide to do.*
>
> Teacher A: *We want two colours. Many of them at the end come up with purple. The planning ... procedure ... end up as a mixed colour. Some of them put one colour and then transfer to another colour. When they presented, some of them said ... cut ... cannot survive.*
>
> Teacher Y: *I did not have this issue as many of them already have read ... even in the prediction of what colour the petals will be. They were able to tell me "half-half". (PD)*

Teacher Y reflected further on how she used questioning to find out students' understanding on plant transport and scientific processes such as hypothesising and variable control. For example, to encourage a deeper understanding of transport in plants, Teacher Y elicited students' own explanations on why water could be transported up the plant but not up a drinking straw. Besides, she probed students' understanding of scientific processes such as predicting and hypothesising while investigating the plant transport system:

> *"They were able to tell me what the xylem tube is. I actually wanted to find out whether they knew what causes the water to move up the tube, as compared to a straw which is like a tube on its own. When you put a straw in water, how come the water does not move up the straw but in the xylem tube it does. They gave their own interpretations which were quite*

interesting. One, they said that water evaporates. That would be similar to the concept of transpiration pull. Some of them talked about the xylem has a lot of spaces and the water going up the spaces. So, I think, quite similar to capillary action. I did not want to go into active transport. Then, we moved on and then I got them to do predictions ... find out the difference between a prediction and a hypothesis. "(PC)

Teacher Y also engaged students in discussing variables in their investigation:

"They wanted to compare celery water intake in classroom and outside. That one, they had some concept of how evaporation affects water uptake in the stem. I told them that in order to do that, they have to think about the variables that they have to keep constant. They were a bit conflicted and frustrated. But I thought it was really good."

In this post lesson discussion, both Teachers A and Y reflected on different aspects of questioning from the earlier post lesson discussions – Teacher A on how questioning facilitated student questioning and Teacher Y on students' understanding of scientific processes.

Comparing the evidence of learning presented so far through the four teachers' enactment and reflection in these two pairs of Primary Four / Five lessons with the first four pairs of Primary Four / Five lessons, Teachers G and J started to include more questioning approaches (Verbal jigsaw; Socratic questioning and Framing) in planning and customising their respective lessons while Teacher A and Y continued to focus on Socratic questioning. Besides, in these latest two pairs of post lesson discussions, new areas of reflection were observed for Teacher G (small group questioning) and Teacher A (student questioning). Teachers J and Y continued to reflect on how they used questioning to promote higher level of thinking and scientific concepts / processes in scientific discourse respectively.

4.1.7   Planning, conducting and reflecting on the fourth pair of lessons

4.1.7.1 Planning, conducting and reflecting on the fourth pair of lessons on light and shadow (Primary Four Teachers G and J)

For the second pair of lessons on light, Teachers G and J also used the "verbal jigsaw", "Socratic questioning" and "framing" questioning approaches in planning and conducting the lesson. When planning for the lesson, like the first lesson, they also identified the curriculum outcomes, phases of lesson development, as well as the key inquiry questions and questioning approaches in Appendix J (Table J-7). They continued to use the lesson plan template suggested at the workshop and planned sub-questions for each key inquiry question.

In the planning and conducting of these next two lessons on light and shadow, Teacher G continued to try out the small group questioning to focus students on analysing data. This is evidence of his previous practice reinforcing his belief of the value of small group questioning and he continued to use small group questioning in his lesson to develop students' analytical skills this time:

> *"So, there was reading and analysing. Because the question was ... what was the difference in shadow between positions two and three? So there was some analysis involved."(PC)*

Besides small group questioning, Teacher G also tried a different strategy in conducting whole class questioning, as compared to his earlier lesson on light and transparency. Instead of merely questioning verbally, he used a combination of the "verbal jigsaw" questioning approach with a concept map during the whole class discussion. When reflecting at the post lesson discussion, both Teachers G and J felt that facilitating the whole class discussion in this manner would prepare students for their home-based learning assignment which required students to draw their own concept maps at the end of the topic. Teacher G highlighted that

the "verbal jigsaw" questioning approach scaffolded students in their thinking of concepts in the topic of light:

> *"They are supposed to do home-based learning - draw a concept map. That would have helped. To give them ideas on how to do the concept map. With guidance ... because it helps them to think. (PC)*

Teacher J also tried a different questioning approach for whole class discussion – summary-based framing questioning approach to end her lesson, something that she did not have time to do in the last lesson. In fact, she adapted Chin's (2007) "Question-based summary" by getting her students to summarise what they have learned rather than summarising the lesson herself. She also shared how she provided further opportunity in this lesson for students to apply their understanding on light and shadow by creating a shadow play. Teacher J's sharing prompted a sharing by Teacher G on how a student in his class applied concepts of shadow in illustrating a bird flying. Their sharing led to a discussion on opportunities for students to apply concepts and think.

Teacher J:	*I should have asked the children to do. He (Teacher G) was telling me he asked one child to do.*
Teacher G:	*Not so much for creating.*
Teacher J:	*If they created the fairy tale stories, that would be creating.*
Teacher G:	*That is creating ... making a story using the concept. Very little creating in the bird. More on application.*
Teacher J:	*Kinesthetic also. (PD)*

In this post lesson discussion, Teachers G and J tried small group questioning and summary-based framing in facilitating small group and whole class scientific discourse respectively. These are questioning approaches that they reflected and wanted to try at the last post lesson discussion.

4.1.7.2 Planning, conducting and reflecting on the fourth pair of lessons on plant processes (Primary Five Teachers A and Y)

For the last lesson on plant processes, Teachers A and Y used "semantic tapestry (focusing and zooming)" in planning and conducting the lesson. When planning for the lesson, like the first lesson, they did not use the lesson plan template suggested at the workshop. They continued to use the school's lesson planning template in Appendix J (Table J-8).

Teacher Y explained that the use of "semantic tapestry" questioning approach was to get students to link key words and phrases in a conceptual framework:

> *"It is more like semantic tapestry. The ideas like what I mentioned are disparate but I am trying to get them to link them together ... the conceptual framework. The linkage was my focus. And in a sense, key words and phrases that they have learned and to associate them to form that mental framework."(PC)*

Besides just focusing on how to use questions to elicit misconceptions like the first two plant lessons, Teacher Y also reflected on how she provided opportunities for students to think of the connections between the different plant processes and ask questions in this last lesson on plant system. This prompted a discussion with Teacher A on their similar objectives in getting students to make connections across topics and systems:

> *Teacher Y:*   *The objective of this whole lesson was to bring them back to the idea that living things require air, food and water to survive and how systems play a part in all these. And to see the links between the systems – how photosynthesis is linked to respiration and how the transport system helps in the process. The focus was to get them to draw a picture. And to elicit misconceptions that they had ... and of which still can be addressed during the discourse. Also to be given the opportunity to ask questions. Many a times when the*

	students learn the topic, they see it as silos. They don't really see the link.
Teacher A:	*For me, it is to be able to see the interconnectedness of the syllabus. Whatever that they have learnt currently is built on whatever they have learnt before. That is why I started off with Primary Three ... the essentials and building up and then moving across. Talk about cells ... then talk about reproduction and finally photosynthesis ... to see that everything fits together.*
Teacher Y:	*Yours was across topics, mine is across systems (PD)*

Besides reflecting on students making connections in scientific discourse, Teachers A and Y reflected and discussed the level of creating involved in this lesson (on making connection between plant processes) and an earlier lesson (on role-playing plant reproduction processes):

Teacher Y:	*They had to draw that picture. I thought it was more creating, may be new ways of looking at things.*
Teacher A:	*I would think the role play creating is lower level or not even creating. They are just creating something to explain.*
Teacher Y:	*It was just an enactment.*
Teacher A:	*It is just something to describe what they understood. This is different. This is creating a bigger idea.*
Teacher Y:	*This is based on what they already know. That one was based on what we gave them.*
Teacher A:	*I think this one is higher order but I don't know whether the role playing one is known as creating. The definition of creating is anything that you create or when you do role play, naturally you have to create the storyline. (PD)*

Teacher A highlighted that post lesson discussions such as this interaction facilitated him in reflecting about student thinking in scientific discourse. This explicit articulation shows that Teacher A found the post lesson pair discussion useful in reflecting on students' thinking:

"Now I am able to when we review ... what are some of the students' thinking. At that point in time, did not think very much about students' thinking. Just to make sure students are on track."(PC)

Overall, when reflecting on the use of questioning, Teacher Y shared the change in her understanding of Socratic questioning as more scaffolding in nature rather than purely higher level thinking. She also added that she now refrains from giving students direct answers and elicits student answers through questioning. This is evidence of Teacher Y's change in knowledge and practice of Socratic questioning:

> *"My idea about Socratic questioning at first was something that has to achieve very deep level thinking. I realise that Socratic questioning need not equate to that. It is more encouraging and scaffolding in nature rather than higher level or higher order thinking questions. I used to think that Socratic questioning was just higher order and once off. The scaffolding process ... the clothes hanger ... just put the different ideas. If you string them together in a ladder ... So, it is a build-up of ideas, instead of the ladder leading them up to the deeper thinking. I feel that I don't give them direct answers ... and see if they can give me the answers instead. It is more conscious effort to try not to give them the answers and to try to achieve that through questioning."(PC)*

In this final post lesson discussion, both Teachers A and Y reflected on changes in their knowledge / practice in questioning. Teacher A highlighted reflecting more about students' thinking while Teacher Y highlighted the change in her understanding and use of Socratic questioning.

Looking at the evidence of learning presented through the four teachers' enactment and reflection for these last pairs of Primary Four / Five lessons, all four teachers were experimenting with a combination of questioning approaches (verbal jigsaw, Socratic questioning and framing for the Primary Four teachers; Socratic questioning and semantic tapestry for the Primary five teachers) in their respective lessons in different lesson contexts. Teachers G and J reflected on the use of small group questioning and summary-based framing respectively. These are areas that they reflected in previous post lesson discussions and wanted to continue using or trying. On the other hand, Teacher Y started reflecting on changes in her understanding of a questioning approach (Socratic questioning)

while Teacher A reflected that the post lesson discussions had facilitated in reflecting about student thinking in scientific discourse.

4.2   Case studies of teachers' learning journeys

In the last Section 4.1, I have identified evidence of teachers' learning through how teachers enacted and reflected on Chin's (2007) framework of questioning approaches (Socratic questioning, verbal jigsaw, semantic tapestry or framing) to promote higher order scientific discourse in different contexts of inquiry activities, from the workshop sessions to the lesson conduct to the post lesson discussions.

In this section, I will analyse evidence of each teacher's learning for change sequences or growth networks across lessons using the interconnected model of teacher professional growth (Clarke and Hollingsworth, 2002; Clarke and Peter, 1993; Teacher Professional Growth Consortium, 1994) in the personal domain (teacher knowledge and beliefs); domain of practice (professional experimentation); domain of consequence (salient outcomes) in relation to the external domain (sources of information or stimulus).

The evidence of learning of each of the four teachers G, J, A and Y will first be presented as change sequences in sections 4.2.1 to 4.2.4. The presentation of the change sequences of the four teachers will facilitate the analysis of patterns in the sequences and identification of growth networks across the four teachers. The common patterns of change sequences and growth networks are next presented in Figure 24 and Figure 25 respectively.

This case study describes Teacher G's learning journey of reflection and enactment in the four domains: the personal domain (teacher knowledge and beliefs), the domain of practice (professional experimentation), the domain of consequences (salient outcomes), and the external domain (sources of information or stimulus).

Teacher G's own illustration of how the learning experiences helped him in enacting and reflecting on questioning

At the end of the entire learning journey, Teacher G was provided a list of experiences that he has undergone and asked to identify the learning experiences that have helped him learn and use questioning to promote higher-order discourse in his science classes. He was also asked to relate in a diagram how he saw the connections between the various learning experiences which have helped him in the process of learning. For instance, if the learning experience helped him to reflect on questioning (knowledge or practice in questioning), he could indicate by drawing a dotted arrow to link the appropriate learning experiences. If the learning experience enabled him to enact questioning (use questioning in practice), he could indicate by drawing a continuous arrow to link the relevant learning experiences.

Teacher G's illustration of the connections between his learning experiences is in Figure 5. A comparison of Teacher G's illustration will be made with the other three teachers' after all four cases are presented.
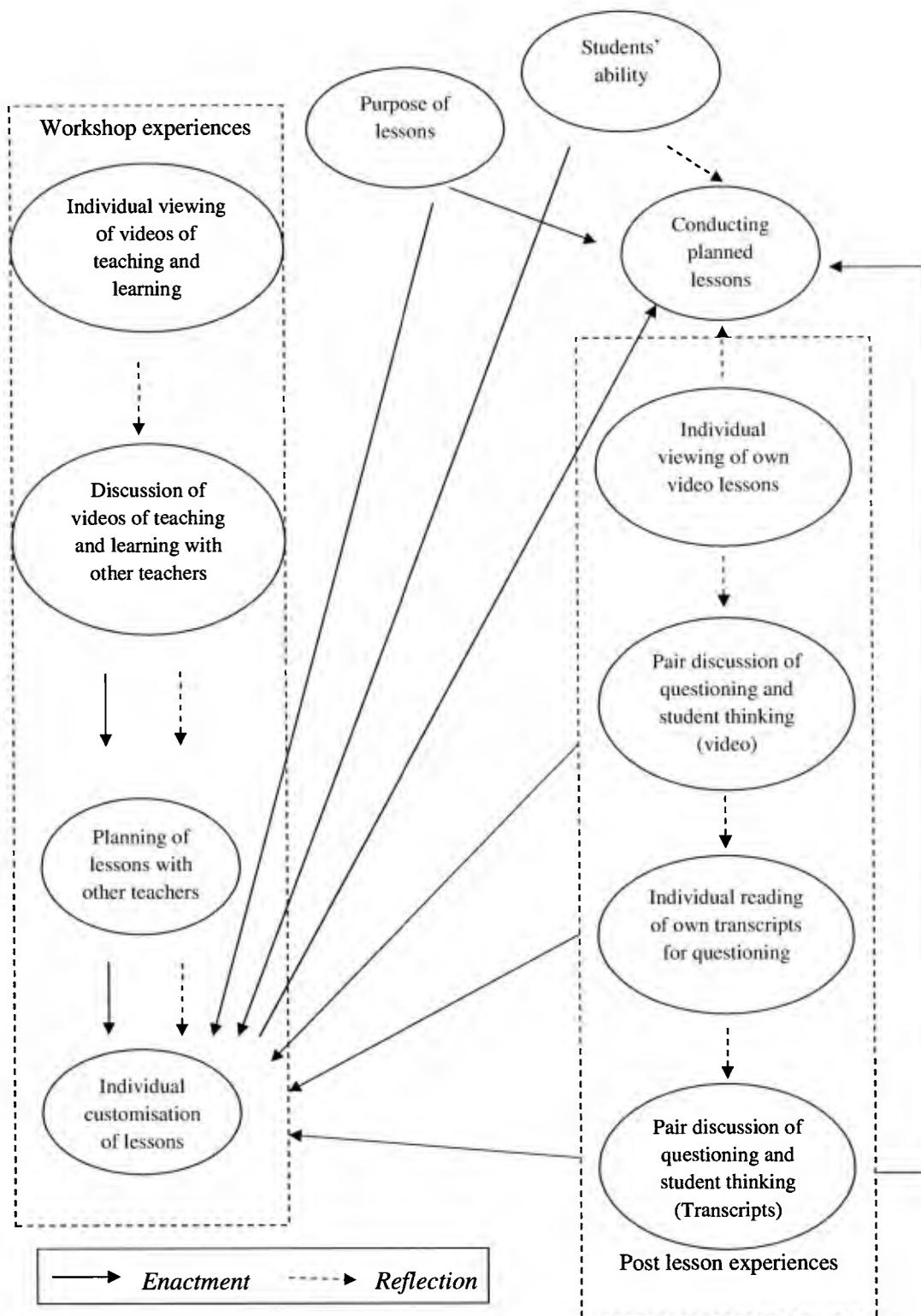
Figure 5. Teacher G's own illustration of enactment and reflection of questioning

Based on Teacher G's illustration of reflection and enactment of questioning, the workshop experiences (both viewing and discussion of video cases as well as lesson planning with other teachers) and post lesson experiences (both individual viewing and pair discussion of own lessons) have helped him in customising and conducting lessons for his students. Using the model of Clarke and Hollingsworth (2002), both the workshop and post lesson experiences can be seen as stimuli (External domain, E) for Teacher G in the professional experimentation of questioning in customising and conducting lessons (Domain of practice, P).

In addition, the purpose of lessons and his students' abilities were key considerations for Teacher G in customising and conducting his lessons. He highlighted that his purpose in conducting student-centred lessons has guided him in customising what he has learned in questioning for his students' learning. These Teacher G's considerations could be seen as the salient outcomes (Domain of consequence, S) that guided him in the professional experimentation of questioning in customising and conducting lesson (Domain of practice, P):

> *"Because it is very much student-centred. My customisation is very student-centred. Based on all that I have learned and I customise to conduct it. That is how I am thinking." (PC)*

A summary of change and growth for Teacher G

Teacher G's own illustration of his reflection and enactment of questioning is broadly aligned to my observation and analysis of his change and growth in questioning. In identifying overall changes / growth for Teacher G, I focused on evidence of changes in knowledge, beliefs, practices and salient outcomes and how these aspects of changes came about through enactment or reflection. Figure 6 shows an overview of changes / growth of Teacher G in the four domains over time: the personal domain, K (teacher knowledge and beliefs), the domain of practice, P (professional experimentation), the domain of consequence, S (salient outcomes), and the external domain, E (sources of

information or stimulus). The mediating processes of enactment and reflection are represented in the model as arrows linking the domains. The mediation arrows are ways of showing how the domain changes come about, not just for showing relationships between the four domains.

- Identified and discussed features of questioning using specific terminologies after introduction to Chin's (2007) questioning framework at workshop (1a)

- Learned from a post lesson discussion that questions can be asked to inculcate values in students (2a)

- Planned and conducted lessons using different questioning approaches, in particular framing, verbal jigsaw and Socratic questioning using the planning template introduced at workshop (1b)

E

1a, 2a   1b

- Reflected and differentiated between framing (prelude) and framing (outline) across two lessons at a post lesson discussion with Teacher J (1c)

K   1c   P
2b, 3a, 4a

- Learned and used questions to promote student cooperation in collecting experimental data in subsequent lessons (2b)
- Believed and used questioning to promote thinking (3a)
- Believed and used small group questioning to promote participation and interaction (4a)

- Reflected and used evidence of students' work to show that questioning (Socratic questioning) can promote student understanding and thinking; as well as how questions can be used in other experimental settings (3c)

3c   3b
4b

S

- Reflected and suggested how questions can be asked differently to promote higher order thinking in scientific discourse (3b)
- Reflected and used small group questioning to uncover and address student misconceptions in subsequent lessons (4b)

⟶ Enactment ----▶ Reflection

Figure 6. An overview of change and growth of Teacher G

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Teacher G's growth network is comprised of four interconnected change sequences. Each change sequence consists of two or more domains together with reflective and / or enactive links connecting these domains:

- Change sequence 1: Acquiring, applying and reflecting on Chin's (2007) questioning approaches
- Change sequence 2: Learning and using questions to inculcate values of cooperation
- Change sequence 3: Believing, using and reflecting on the use of questioning to promote thinking
- Change sequence 4: Believing, using and reflecting on the use of small group questioning for formative assessment

Change sequence 1: Acquiring, applying and reflecting on Chin's (2007) questioning approaches

After the introduction of Chin's (2007) framework of questioning approaches at the workshop itself, Teacher G started to identify questioning approaches and discuss their features using specific questioning terminologies during the analysis of videos of teaching and learning (see 1a).

Teacher G also planned and conducted lessons using different questioning approaches, in particular framing, verbal jigsaw and Socratic questioning using the planning template introduced at the workshop (see 1b).

At a subsequent post lesson reflection and discussion with Teacher J, besides continuing to use the questioning terminologies to identify and discuss his own videos and transcripts of lessons on heat, Teacher G was also able to compare and further differentiate between the sub-questioning approaches (framing prelude and framing outline) used in two different lesson contexts with Teacher J (see 1c).

The change sequence for Teacher G's acquisition, application and reflection on Chin's (2007) questioning approaches is summarised in Figure 7 below:
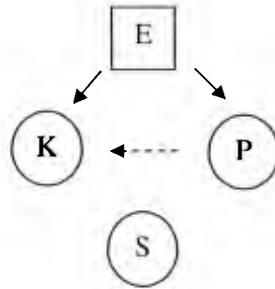
Figure 7. Teacher G's change sequence on acquisition, application and reflection on Chin's (2007) questioning approaches

Change sequence 2: Learning and using questions to inculcate values of cooperation

Besides acquiring, applying and reflecting on Chin's (2007) questioning approaches introduced at the workshop, Teacher G highlighted that he learned at a post lesson discussion that questions can be used to inculcate values such as cooperation in collecting experimental data (see 2a) and he applied this new learning in subsequent lessons (see 2b). This shows a change in his knowledge / belief, now valuing the promotion of student cooperation using questioning which he was unaware of previously.

The change sequence for Teacher G's learning and using questions to inculcate values of cooperation is summarised in Figure 8 below:
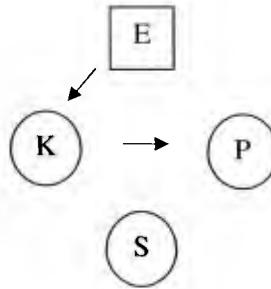
Figure 8. Teacher G's change sequence on learning and using questions to inculcate values of cooperation

Change sequence 3: Believing, using and reflecting on the use of questioning to promote thinking

At the questioning workshop, Teacher G shared his belief on the role of questioning to promote student thinking. In subsequent planning and conducting of lessons on heat and light, he provided opportunities for students to apply concepts and skills through hands-on investigations (heat transfer and conduction in different materials as well transparency of different materials and variables affecting shadow formation) and applications in real life contexts. As he planned these learning experiences, he also planned key questions to ask during the lessons (see 3a).

At the post lesson reflection and discussions of these lessons, Teacher G suggested how questions could be asked differently to promote higher order thinking in scientific discourse (see 3b). This shows Teacher G reflecting on his practice, now valuing the promotion of higher order thinking as part of his teaching goals and how he can actually make it happen during scientific discourse. Besides, he not only used evidence of students' work to show that the

"Socratic questioning" questioning approach can promote student understanding and thinking but also suggested that the questions that he asked can be used in future lessons with experimental settings (see 3c).

The change sequence for Teacher G's belief, use and reflection on the use of questioning to promote thinking is summarised in Figure 9 below:
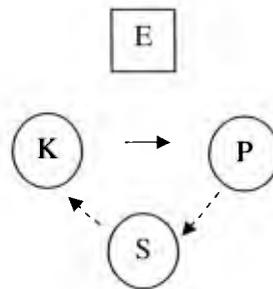
Figure 9. Teacher G's change sequence on believing, using and reflecting on the use of questioning to promote thinking

Change sequence 4: Believing, using and reflecting on the use of small group questioning for formative assessment

At the questioning workshop, besides sharing his belief on the role of questioning to promote student thinking, Teacher G also highlighted using questioning for formative assessment.

Both his belief as well as observations and reflections on the limitations of whole class questioning in the first two lessons on heat led him to try out small group questioning in the subsequent lessons on light (See 4a). He affirmed the usefulness of small group questioning to better uncover student misconceptions in the first lesson on light and continued using small group questioning in the second lesson on light (See 4b). This again shows how his reflection on the new practice in group questioning helped to uncover students' misconceptions and to deal with them constructively.

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The change sequence for Teacher G's belief, use and reflection on the use of small group questioning for formative assessment is summarised in Figure 10 below:
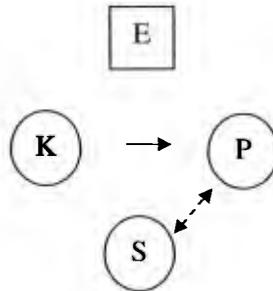
Figure 10. Teacher G's change sequence on believing, using and reflecting on the use of small group questioning for formative assessment

The change sequences of Teacher G will be compared with the change sequences of Teachers J, A and Y to identify common change sequences and growth networks in Section 4.3.

4.2.2   Case study of Teacher J

Teacher J's own illustration of how the learning experiences helped her in enacting and reflecting on questioning

At the end of the entire learning journey, like Teacher G, Teacher J was provided a list of experiences that she has undergone and asked to identify the learning experiences that have helped her learn and use questioning to promote higher order discourse in her science classes. She was also asked to relate in a diagram how she saw the connections between the various learning experiences which have helped her in the process of learning.

Teacher J's illustration of the connections between her learning experiences is in Figure 11. A comparison of Teacher J's illustration will be made with the other three teachers' after all four cases are presented.
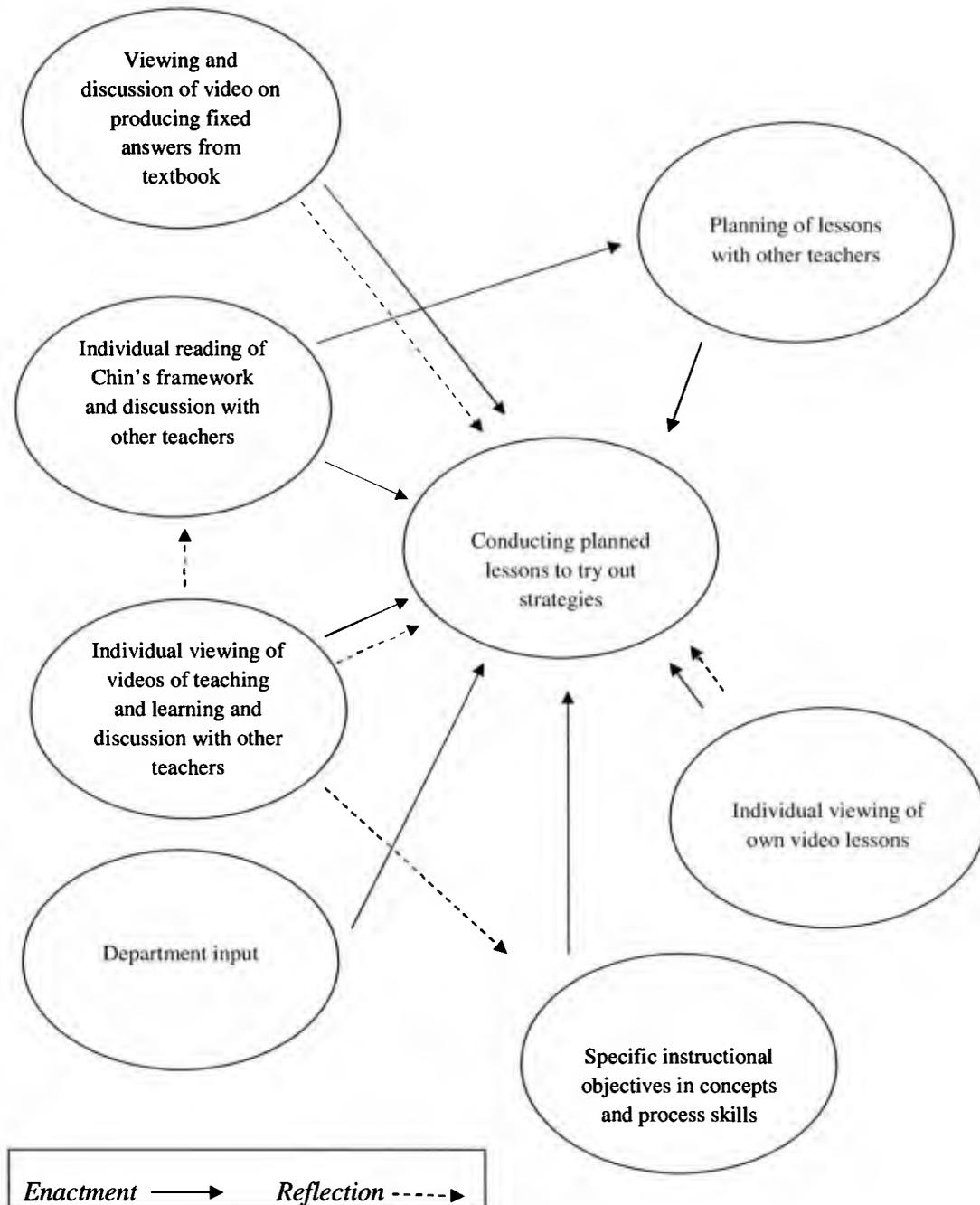
Figure 11. Teacher J's own illustration of enactment and reflection of questioning

Based on Teacher J's illustration of reflection and enactment of questioning, the workshop experiences (both viewing and discussion of video cases as well as lesson planning with other teachers) and post lesson experiences (particularly the individual viewing of her own video) have helped her in conducting lessons for her students. Using the model of Clarke and Hollingsworth (2002), both the workshop and post lesson experiences can be seen as stimuli (External domain, E) for Teacher J in the professional experimentation of questioning in conducting lessons (Domain of practice, P). Comparing the illustrations of Teacher J and Teacher G, the learning experiences have influenced both teachers' professional experimentations. However, the various learning experiences seemed to have influenced Teacher J more in her actual conduct of lessons and Teacher G more in his planning / customisation of lessons.

In addition, Teacher J included in her illustration two other considerations that also influenced her conduct of lessons - the specific instructional objectives (concepts and process skills) and department input. These considerations are different from Teacher G's considerations. Teacher G highlighted the purpose of lesson and students' abilities instead. For Teacher G, his purpose in conducting student-centred lessons has guided him in customising what he has learned in questioning for his students' learning. The salient outcomes (Domain of consequence, S) were more explicitly expressed in Teacher G's illustration.

A summary of change and growth for Teacher J

Teacher J's own illustration of her reflection and enactment of questioning is broadly aligned to my observation and analysis of her change and growth in questioning. Figure 12 shows an overview of changes / growth of Teacher J in the four domains over time: the personal domain, K (teacher knowledge and beliefs), the domain of practice, P (professional experimentation), the domain of consequence, S (salient outcomes), and the external domain, E (sources of information or stimulus).

- Identified examples, provided own perspectives and asked questions on the questioning approaches using specific terminologies after introduction to Chin's (2007) questioning framework at workshop **(1a)**

- Planned and conducted lessons using different questioning approaches, in particular framing, verbal jigsaw, Socratic questioning using the planning template introduced at workshop **(1b)**

E

- Learned from a workshop case study that semantic tapestry and role play can be used to help students understand the concept of Sun as an energy source **(2a)**

1a, 2a

1b
3d

- Reflected on how the scenario used in one of the lessons was improved at a science committee discussion to promote higher order thinking **(3d)**

- Reflected and differentiated between framing (prelude) and framing (outline) across two lessons at a post lesson discussion with Teacher G **(1c)**

K ◄------------------ **1c** ------------------- **P**
_____ **2b, 3a** _____►

- Applied semantic tapestry and role play to promote student understanding in another topic of heat **(2b)**
- Believed and used Socratic questioning (constructive challenge) to manage students' responses, though not planned in the original lesson plan **(3a)**

- Reflected that she liked how framing helped students connect between previous and new experiments. Also reflected that students' misconceptions were better addressed using a combination of framing with Socratic questioning (reflective toss) **(1e)**

1e, 3c

1d, 2c, 3b

S

- Reflected on how framing helped students to make connections to previous and upcoming experiments; and addressed students' misconceptions when used with Socratic questioning (reflective toss) **(1d)**

- Reflected on the importance of how a question is posed and that different questions can be used at different parts of a lesson. She particularly affirmed the value of Socratic questioning (constructive challenge) in promoting student thinking, based on evidence of students' thinking in their verbal responses in given scenarios **(3c)**

- Reflected on how the use of semantic tapestry and role play that she learned at the workshop helped her to address students' difficulties and prepare them for assessment in heat gain / lost **(2c)**

- Reflected on how the use of Socratic questioning (constructive challenge) and scenarios supported students to think and create solution; and how students' thinking could be further extended by self-evaluating the accuracy of data from the datalogger **(3b)**

| ———► Enactment   -----► Reflection |

Figure 12. An overview of change and growth of Teacher J

Teacher J's growth network is comprised of three interconnected change sequences. Each change sequence consists of two or more domains together with reflective and / or enactive links connecting these domains:

- Change sequence 1: Acquiring, applying and reflecting on Chin's (2007) questioning approaches
- Change sequence 2: Learning, using and reflecting on a combination of questioning (semantic tapestry) and pedagogy (role play) to promote student understanding of concepts
- Change sequence 3: Believing, using and reflecting on the use of Socratic questioning (constructive challenge) and scenarios to promote thinking in scientific discourse

Change sequence 1: Acquiring, applying and reflecting on Chin's (2007) questioning approaches

After the introduction of Chin's (2007) framework of questioning approaches at the workshop itself, Teacher J started to identify examples, provide own perspectives and ask questions on the questioning approaches using specific terminologies during the analysis of videos of teaching and learning (see 1a). Teacher J also planned and conducted lessons using different questioning approaches, in particular framing, verbal jigsaw and Socratic questioning using the planning template introduced at the workshop (see 1b).

At a post lesson discussion with Teacher G, besides continuing to use the questioning terminologies to discuss their videos and transcripts of lessons on heat, Teacher J was also able to compare and further differentiate between strategies of the "framing" questioning approach (framing prelude and framing outline) used in two different lesson contexts (see 1c). She also reflected on how the "framing" questioning approach helped students to make connections to previous and upcoming experiments; and addressed students' misconceptions when used with the "Socratic questioning (reflective toss)" questioning approach

(see 1d). Besides, she added that she liked how the "framing" questioning approach helped students connect between previous and new experiments and acknowledged that students' misconceptions were better addressed using a combination of "framing" with "Socratic questioning (reflective toss)" questioning approaches (see 1e).

The change sequence for Teacher J's acquisition, application and reflection on Chin's (2007) questioning approaches is summarised in Figure 13 below:
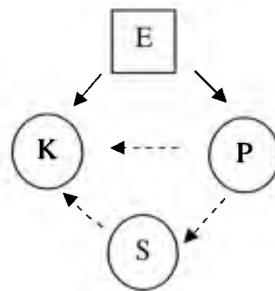
Figure 13. Teacher J's change sequence on acquisition, application and reflection on Chin's (2007) questioning approaches

Change sequence 2: Learning, using and reflecting on a combination of questioning (semantic tapestry) and pedagogy (role play) to promote student understanding of concepts

Besides acquiring, applying and reflecting on Chin's (2007) questioning approaches introduced at the workshop, Teacher J highlighted that she learned from a workshop case study that the "semantic tapestry" questioning approach and the "role play" pedagogy can be used to help students understand the concept of Sun as an energy source (see 2a). She applied the combination of "semantic tapestry" questioning approach cum "role play" pedagogy when conducting a lesson on heat to promote student understanding of heat gain and loss (see 2b).

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She reflected on how the use of the questioning approach with pedagogy helped her to address students' difficulties and prepare them for assessment (2c). This shows her valuing the use of a combination of questioning with pedagogy to develop conceptual understanding, something that she was unaware of previously.

The change sequence for Teacher J's learning, use and reflection on a combination of questioning (semantic tapestry) and pedagogy (role play) to promote student understanding of concepts is summarised in Figure 14 below:
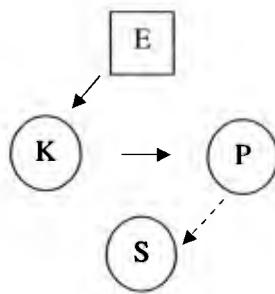
Figure 14. Teacher J's change sequence on learning, using and reflecting on a combination of questioning (semantic tapestry) and pedagogy (role play)

Change sequence 3: Believing, using and reflecting on the use of Socratic questioning (constructive challenge) and scenarios to promote thinking in scientific discourse

At the questioning workshop, Teacher J shared her belief on the role of questioning to interest and engage pupils as well as promote student understanding, thinking and students' questions. In subsequent conducting of lessons on heat and light, she provided opportunities for students to apply concepts and skills through hands-on investigations (heat transfer and conduction in different materials as well transparency of different materials and variables affecting shadow formation) and applications in real life contexts. During these lessons, based on students' responses arising from scientific discourse, she used

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the "Socratic questioning (constructive challenge)" questioning approach which she did not include at the lesson planning stage. She wanted to encourage students to suggest their own answers instead of providing them with the answers (see 3a).

At the post lesson reflection and discussion of these lessons, Teacher J identified areas she had done well and areas she could improve on. For instance, Teacher J identified how the planned scenarios provided opportunities for students' higher order thinking in scientific discourse. While reflecting, she was able to identify lesson attributes which supported higher order thinking and suggest how she could further extend students' thinking. For example, she reflected that she could have asked students to evaluate the accuracy of datalogger readings instead of telling them that the readings were inaccurate (see 3b). Overall, she concluded on the importance of how a question is posed and that different questions can be used at different parts of a lesson (3c). This is something she wanted to learn at the day one workshop. Besides gleaning insights from trying out questioning in her class, she also shared how a science committee discussion has helped her in improving the design of the lesson to promote higher order thinking in scientific discourse (3d).

The change sequence for Teacher J's belief, use and reflection on the use of Socratic questioning (constructive challenge) and scenarios to promote thinking in scientific discourse is summarised in Figure 15 below:
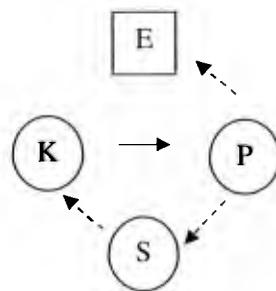
Figure 15. Teacher J's change sequence on believing, using and reflecting on the use of Socratic questioning and scenarios to promote thinking

The change sequences of Teacher J will be compared with the change sequences of Teachers G, A and Y to identify common change sequences and growth networks in Section 4.3.

4.2.3 Case study of Teacher A

Teacher A's own illustration of how the learning experiences helped him in enacting and reflecting on questioning

At the end of the entire learning journey, Teacher A was provided a list of experiences that he has undergone and asked to identify the learning experiences that have helped him learn and use questioning to promote higher order discourse in his science classes. He was also asked to relate in a diagram how he saw the connections between the various learning experiences which have helped him in the process of learning.

Teacher A's illustration of the connections between his learning experiences is in Figure 16. A comparison of Teacher A's illustration will be made with the other three teachers' after all four cases are presented.
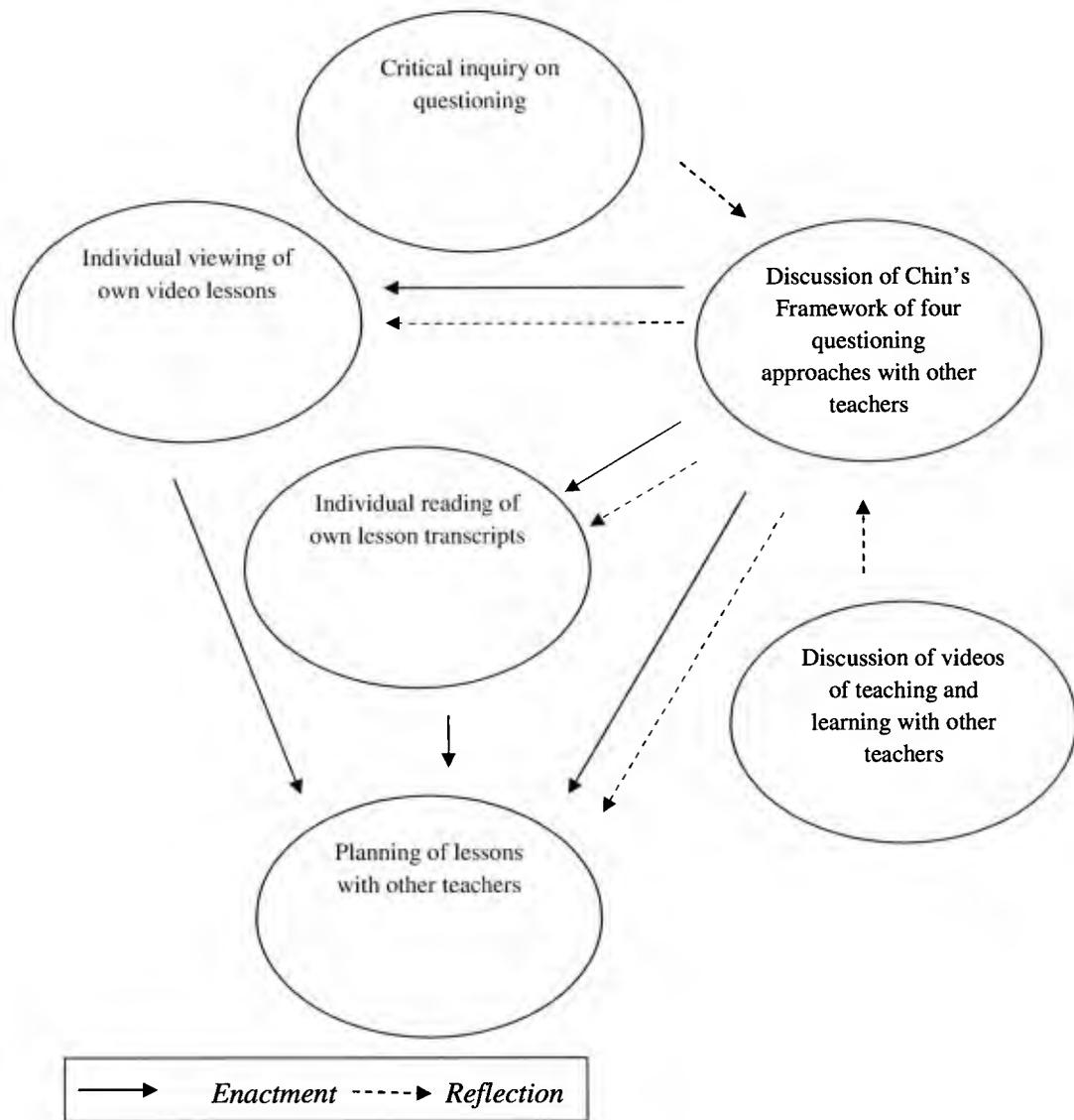
Figure 16. Teacher A's own illustration of enactment and reflection of questioning

Based on Teacher A's illustration of reflection and enactment of questioning, the discussion of Chin's framework, the individual reading of own transcripts and the viewing of own video with other teachers have helped him in planning lessons for his students. Using the model of Clarke and Hollingsworth (2002), both the workshop and post lesson experiences as well as other exposure to questioning in "critical inquiry on questioning course" can be seen as stimuli

(External domain, E) for Teacher A in the professional experimentation of questioning in planning lessons (Domain of practice, P).

Amongst the four teachers, Teacher A is the only one who did not include the conducting of lessons as one of the useful learning experiences. He perceived the conduct of lessons as just carrying out the planned lesson and expressed that he learned most when he reflected on what was done:

> *"To me, conducting is just the carrying out of the experience. The thing I learn most is when I look at it and think of what I have done. The conducting is just the carrying out of lesson. To me, that one is an everyday thing. For me, reflecting on lesson discussions on what I actually pick out; how it actually aligns itself to the approaches and what are some strategies used that I am also not conscious of. I benefit the most out of the period of time."(PC)*

Besides, he shared that during the period of working together, he was more conscious of the questioning strategies and has questioned himself on how to better engage students and encourage student questioning. He also stressed the importance of helping students appreciate the big ideas and link concepts across topics and levels. These Teacher A's considerations can be seen as the salient outcomes (Domain of consequence, S) that guided him in the planning of questioning (Domain of practice, P).

> *"More heightened awareness of the strategies that I use in class. Before this, we were not very conscious about the questioning strategies, even though we use. This period of time, the observation caused me to always asking myself. How do I get students to ask questions more? How do I get them to be more involved? For me, it is to be able to see the interconnectedness of the syllabus. Whatever that they have learned currently is built on whatever they have learned before. We also want them to do constant linkages. To see that everything fits together, not just in parts."(PC)*

A summary of change and growth for Teacher A

Teacher A's own illustration of his reflection and enactment of questioning is broadly aligned to my observation and analysis of his change and growth in questioning. Figure 17 shows an overview of changes / growth of

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Teacher A in the four domains over time: the personal domain, K (teacher knowledge and beliefs), the domain of practice, P (professional experimentation), the domain of consequence, S (salient outcomes), and the external domain, E (sources of information or stimulus).

- Discussed and questioned differences between questioning approaches using specific terminologies after introduction to Chin's (2007) questioning framework at workshop **(1a)**

E

1a   **1b**

- Planned and conducted lessons using Socratic questioning, semantic tapestry (focusing-zooming) and the school's lesson planning template **(1b)**

- Believed and used questioning to promote student questioning and thinking **(2a)**

K   **2a**   **P**
               1c, 1e

- Reflected and differentiated between Socratic questioning and semantic tapestry (focusing and zooming) at a post lesson discussion of his own "plant process" lesson, something he questioned at the workshop **(1c)**

- Reflected on whether questioning approaches can be tagged to topics / lessons to facilitate teachers' use **(1e)**

- Reflected on the potential of students' questions in promoting thinking and how strategies such as revoicing can be used in actual practice to cope with students' questions **(2c)**

2c

1d, 2b

S

- Reflected on how Socratic questioning, semantic questioning (focusing and zooming) were used to develop big ideas and interconnections between concepts **(1d)**

- Reflected on how questioning could engage students to ask questions and think **(2b)**

⟶ *Enactment*   ----▸ *Reflection*

Figure 17. An overview of change and growth of Teacher A

Teacher A's growth network is comprised of two interconnected change sequences. Each change sequence consists of two or more domains together with reflective and / or enactive links connecting these domains:

- Change sequence 1: Acquiring, applying and reflecting on Chin's (2007) questioning approaches – Socratic questioning and semantic tapestry (focusing and zooming) to appreciate big ideas and make connections between concepts
- Change sequence 2: Believing, using and reflecting on the use of questioning to promote student questioning and thinking

Change sequence 1: Acquiring, applying and reflecting on Chin's (2007) questioning approaches – Socratic questioning and semantic tapestry (focusing and zooming) to appreciate big ideas and make connections between concepts

After the introduction of Chin's (2007) questioning framework at the workshop itself, Teacher A started to discuss and question differences between questioning approaches (Socratic questioning as well as semantic tapestry (focusing and zooming) using specific terminologies during the analysis of videos of teaching and learning (see 1a).

Teacher A also planned and conducted lessons using different questioning approahes, in particular Socratic questioning as well as semantic tapestry (focusing and zooming) using the school's lesson planning template, instead of the one introduced at the workshop (see 1b).

At a subsequent post lesson reflection and discussion with Teacher Y, Teacher A differentiated between the "Socratic questioning" and "semantic tapestry (focusing and zooming)" questioning approaches at a post lesson discussion of his own "plant process" lesson, something he questioned at the workshop (see 1c). He also reflected on how both questioning approaches helped in developing big ideas and interconnections between concepts (see 1d). At the last post lesson discussion, he suggested tagging questioning approaches to topics or lessons to facilitate teachers' use in the future (see 1e). This shows a change in

his belief, from not focusing on planning questioning to now valuing the planning of specific questioing approaches in promoting student outcomes for different topics.

The change sequence for Teacher A's acquisition, application and reflection on Chin's (2007) questioning approaches is summarised in Figure 18 below:
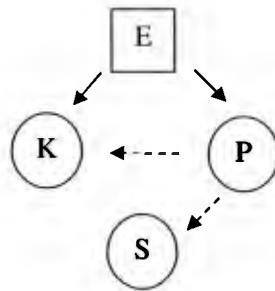
Figure 18. Teacher A's change sequence on acquisition, application and reflection on Chin's (2007) questioning approaches

Change sequence 2: Believing, using and reflecting on the use of questioning to promote student questioning and thinking

At the questioning workshop, Teacher A shared his belief on the role of questioning to promote student questioning and thinking. When planning the lesson on plant transport, he provided opportunities for students to ask question, based on their friends' investigative plans. Besides, he also planned key questions to ask during the lesson (see 2a).

At the post lesson reflection and discussion of these lessons, Teacher A reflected on how questioning engaged students to ask questions and think (see 2b). This shows him valuing the planning of questioning to promote student questions and thinking after seeing how it actually happened in his own

classroom. Besides, he illustrated how strategies such as revoicing (Chin, 2007) can be used in actual practice to cope with students' questions (see 2c).

The change sequence for Teacher A's belief, use and reflection on the use of questioning to promote student questioning and thinking is summarised in Figure 19 below:
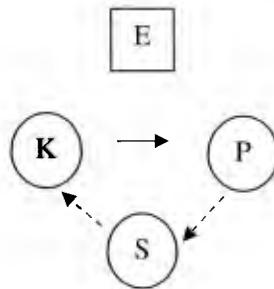
Figure 19. Teacher A's change sequence on believing, using and reflecting on the use of questioning to promote student questioning and thinking

The change sequences of Teacher A will be compared with the change sequences of Teachers G, J and Y to identify common change sequences and growth networks in Section 4.3.

4.2.4 Case study of Teacher Y

Teacher Y's own illustration of how the learning experiences helped her in enacting and reflecting on questioning

At the end of the entire learning journey, Teacher J was provided a list of experiences that she has undergone and asked to identify the learning experiences that have helped her learn and use questioning to promote higher-order discourse in her science classes. She was also asked to relate in a diagram how she saw the connections between the various learning experiences which have helped her in the process of learning.

Teacher Y's illustration of the connections between her learning experiences is in Figure 20. A comparison of Teacher Y's illustration will be made with the other three teachers' after all four cases are presented.
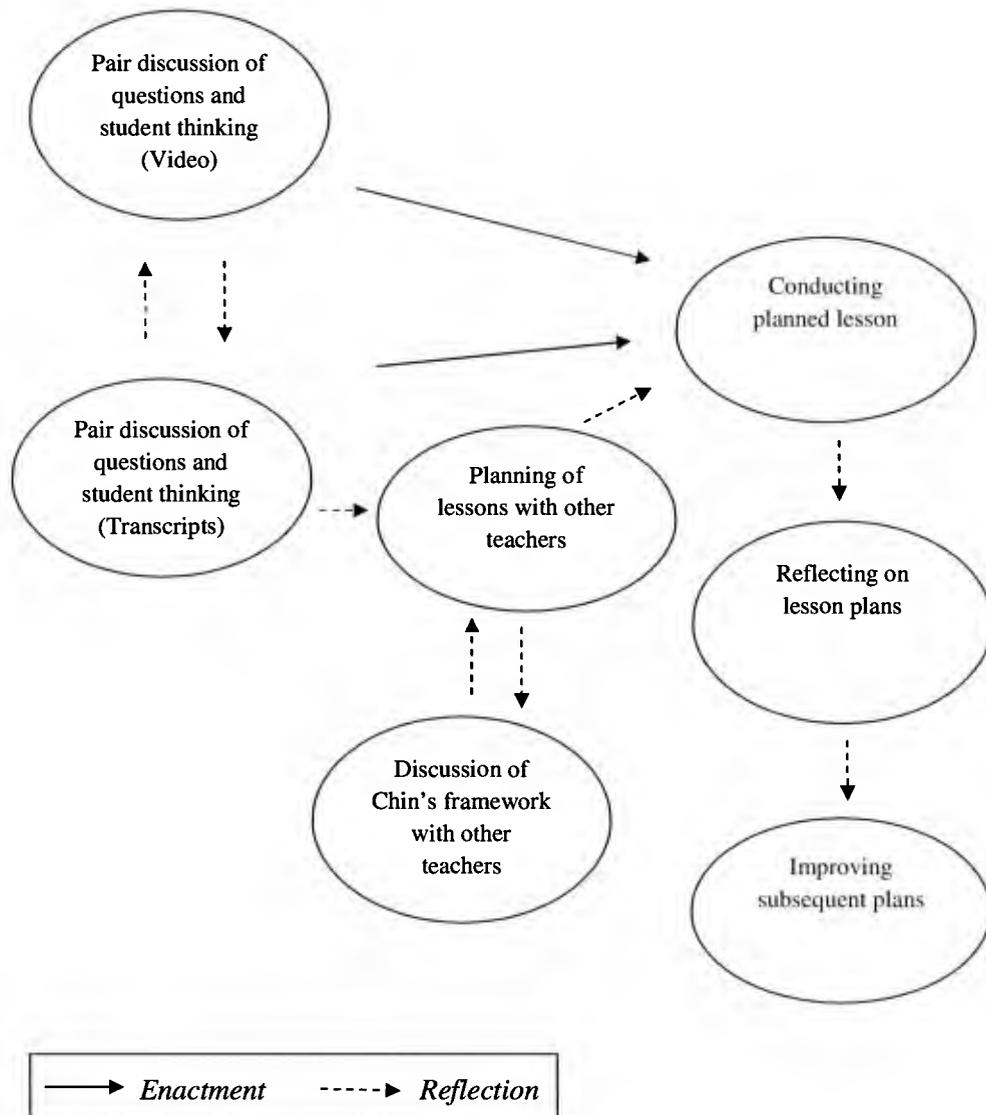
Figure 20. Teacher Y's own illustration of enactment and reflection of questioning

Based on Teacher Y's illustration of reflection and enactment of questioning, the workshop experiences (discussion of Chin's framework and lesson planning

with other teachers) and post lesson experiences (both pair discussion of own videos and transcripts of lessons) have helped her in conducting lessons for her students. Using the model of Clarke and Hollingsworth (2002), both the workshop experiences and the post lesson experiences can be seen as stimuli (External domain, E) for Teacher Y in the professional experimentation of questioning in conducting lessons (Domain of practice, P). Like Teacher J, the learning experiences have impacted Teacher Y's actual conduct of lesson.

> *"I have this (questioning) framework in mind. I use that in the discussion of planning of lessons. This is the reflecting. It is a back and forth thing for me. As you collaborate and plan, it is like you still have to refer back to the framework. This collaboration comes in as a link point between reflecting about the pair discussion using the videos and the transcripts and conducting of the planned lessons. In order to see the transcripts in real time and to refer back to the video. Reflecting going on there. Both these allowed me in conducting my planned lesson. So, it is enactment ... the conduct will better allow me to reflect on subsequent lessons. Improving subsequent plans."*

A summary of change and growth for Teacher Y

Teacher Y's own illustration of her reflection and enactment of questioning is broadly aligned to my observation and analysis of her change and growth in questioning. Figure 21 shows an overview of changes / growth of Teacher Y in the four domains over time: the personal domain, K (teacher knowledge and beliefs), the domain of practice, P (professional experimentation), the domain of consequence, S (salient outcomes), and the external domain, E (sources of information or stimulus).
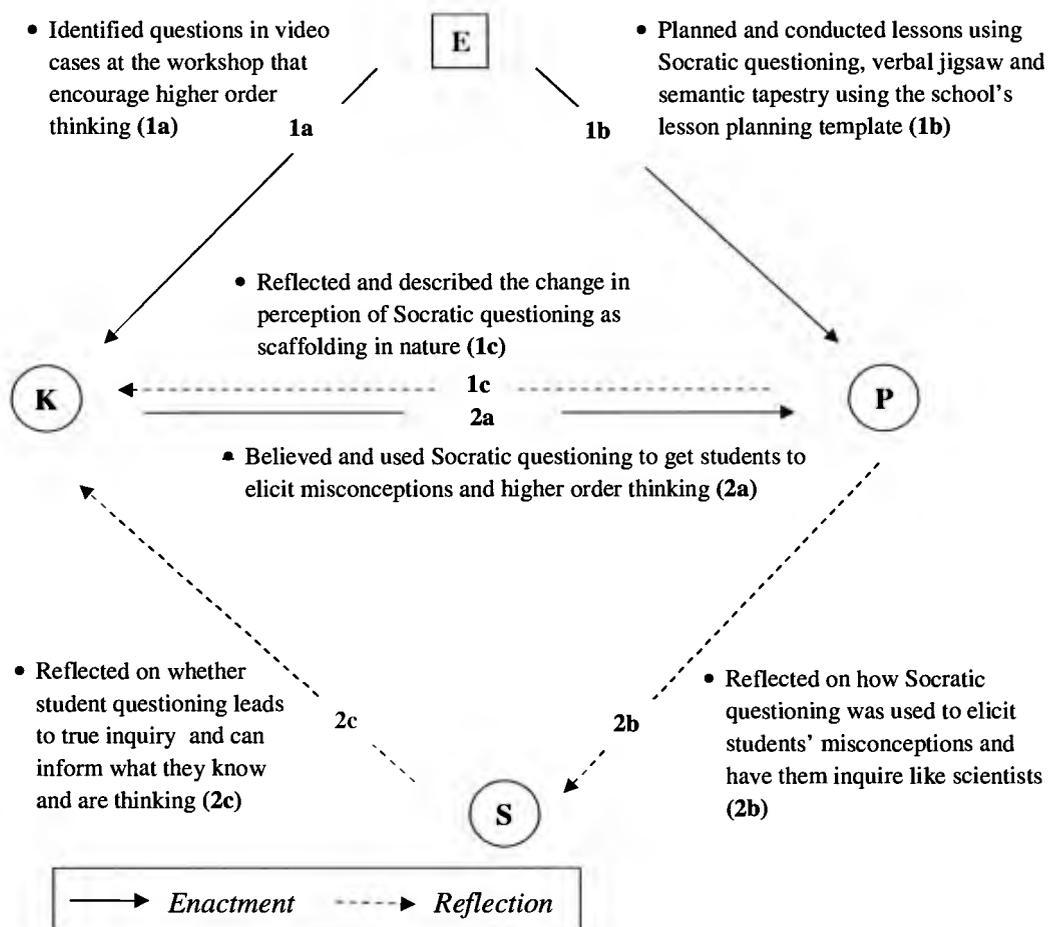
Figure 21. An overview of change and growth of Teacher Y

Teacher Y's growth network is comprised of two interconnected change sequences. Each change sequence consists of two or more domains together with reflective and / or enactive links connecting these domains:

- Change sequence 1: Acquiring, applying and reflecting on Chin's (2007) questioning approaches

- Change sequence 2: Believing, using and reflecting on the use of Socratic questioning to identify students' misconceptions and promote thinking

Change sequence 1: Acquiring, applying and reflecting on Chin's (2007) questioning approaches

After the introduction of Chin's (2007) questioning framework at the workshop itself, Teacher Y started to identify questions in video cases at the workshop that encourage higher order thinking using specific questioning terminologies during the analysis of videos of teaching and learning (see 1a).

Teacher Y also planned and conducted lessons using the "Socratic questioning", "verbal jigsaw" and "sematic tapestry" questioning approaches using the school's lesson planning template, instead of the one introduced at the workshop (see 1b).

At a post lesson reflection, Teacher Y reflected and described the change in her perception of Socratic questioning as scaffolding in nature, rather than just focused on higher order thinking (see 1c).

The change sequence for Teacher Y's acquisition, application and reflection on Chin's (2007) questioning approaches is summarised in Figure 22 below:
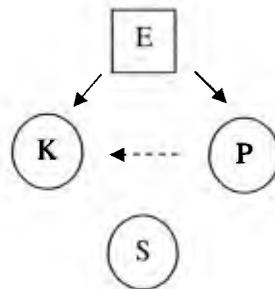
Figure 22. Teacher Y's change sequence on acquisition, application and reflection on Chin's (2007) questioning approaches

Change sequence 2: Believing, using and reflecting on the use of Socratic questioning to identify students' misconceptions and promote thinking

Besides acquiring, applying and reflecting on Chin's (2007) questioning approaches introduced, Teacher Y stated her belief in using questions to elicit misconceptions and higher order thinking in scientific discourse at the workshop itself (see 2a).

At the post lesson reflection and discussions of these lessons, Teacher Y reflected on how Socratic questioning was used to elicit students' misconceptions and have them inquire like scientists, including student questioning in scientific discourse (see 2b). She further reflected on whether student questioning leads to true inquiry and can inform what they know and are thinking (see 2c). This shows her now valuing the role of student questioning in the actual inquiry process.

The change sequence for Teacher Y's belief, use and reflection on the use of questioning to promote student questioning and thinking is summarised in Figure 23 below:
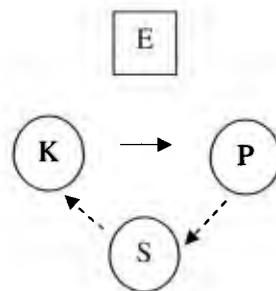
Figure 23. Teacher Y's change sequence on believing, using and reflecting on the use of questioning to promote student questioning and thinking

The change sequences of Teacher Y will be compared with the change sequences of Teachers G, J and A to identify common change sequences and growth networks in Section 4.3.

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4.3   Comparison of teachers' change and growth

Based on the analysis of the change sequences and growth networks of all four teachers, all the teachers were found to change some aspects of their knowledge (K), practice (P) and / or salient outcomes (S) but to different extents. This is evident through the enactment of questioning approaches in the classrooms and reflection of questioning in promoting higher order scientific discourse during post lesson discussion of transcripts and videos.

The process by which change occurs was represented as the "change sequence", consisting of two or more domains (K, P or S) together with reflective and enactive links connecting these domains. A change sequence associated with more lasting change is termed a "growth network".

4.3.1 Change sequences of teachers

Based on the analysis of changes sequences and growth networks of the four teachers G, J, A and Y, seven types of change sequences were found within the growth networks in Figure 24.

Among the seven types of change sequences, some change sequences involve two domains (e.g. how the stimulus E is connected to practice (P) or to knowledge (K) while others involve three domains (e.g. how the stimulus E is linked to practice (P) and to salient outcomes (S)).

Based on the four case studies of Teachers G, J, A and Y presented in section 4.2, various combinations of seven change sequences were found across the four cases. Some of the change sequences were common among the four teachers while some were unique to individual teachers.
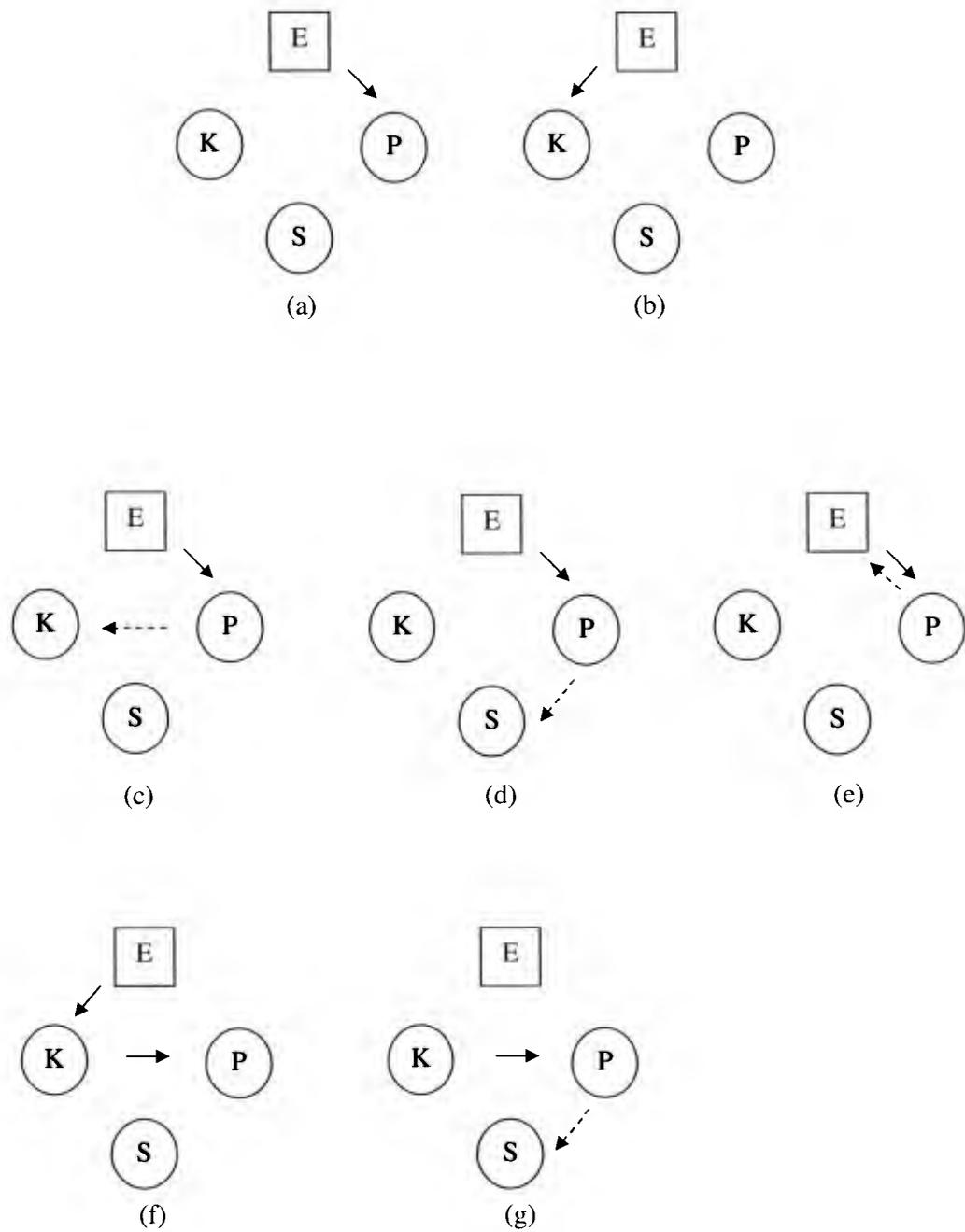
Figure 24. Patterns of change sequences across the four teachers

The teachers' experimentation with Chin's questioning framework introduced at the workshop was the common change sequence among the four teachers. The change in the external domain "E" was linked through enactment to change in the domain of practice "P" (see Figure 24a) in the questioning approaches that the teachers planned and used in their lessons respectively. Besides, as Chin's framework was new to all four teachers, all four teachers were found to apply specific terminologies from the framework in analysing video cases presented at the workshop (see Figure 24b) after the framework was introduced and continued to enact the questioning approaches in their lessons (see Figure 24f).

Following changes in practice, some teachers reflected on their knowledge and / or belief (personal domain, K) of Chin's framework of questioning approaches (Figure 24c), rather than evaluate the quality of their practice as reported by Clarke and Hollingsworth (2002). Other teachers reflected on the salient outcomes (domain of consequence, S) such as students' level of thinking following their experimentation of the questioning approaches (domain of practice, P) in Figure 24d. One of the teachers, Teacher J, also reflected on other external stimuli (external domain, E) such as discussions at departmental meetings which contributed to her practice (Figure 24e).

Finally, among the change sequences, one of the change sequences (Figure 24g) was not linked directly to the external stimuli (external domain, E). In this case, the changes occurred without the direct influence of the workshop. The knowledge domain "K" was linked through enactment to change in the domain of practice "P". Teachers were also found to reflect on the salient outcomes (domain of consequence, S) such as students' level of thinking following their experimentation of the questioning approaches (domain of practice, P).

Change sequences in Figures 24a, 24c and 24d were also reported by Clarke and Hollingsworth (2002) while those in Figures 24b, 24e, 24f and 24g were observed in this study. Hence, this study has surfaced four new change

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sequences, contributing to the understanding of teacher change using the interconnected model of growth of Clarke and Hollingsworth (2002).

4.3.2 Growth networks of teachers

Some of these change sequences went further as there was evidence of changes initiated in practice across the various lessons. Figure 25 shows three different growth networks for the four teachers, comprising different combinations of changes sequences in Figure 24. Figure 25a represents the growth network pattern of Teachers A and Y while Figures 25b and 25c show the network patterns of Teacher G and J respectively. While there are three main growth network patterns, the number of change sequences for a similar network pattern varied. This shows that teacher learning can occur through a variety of networks as detailed earlier in Figures 6, 12 17 and 21, suggesting that professional development should be deliberately designed to offer participants the opportunity to enact change in a variety of forms and change sequences consistent with individual inclinations (Clarke & Hollingsworth, 2002).
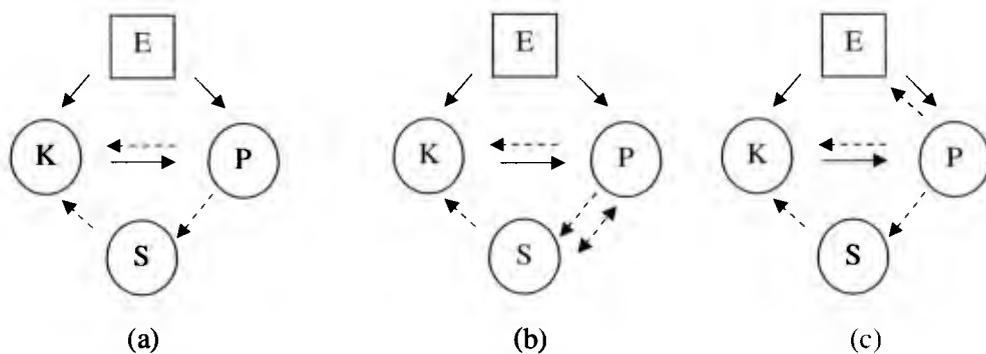
Figure 25. Patterns of growth networks across the four teachers

Based on the analysis of the change sequences and growth networks of the teachers, I have gained insights into how teachers' learning are supported through reflection and enactment across a combination of various learning experiences, which is lacking in some existing professional development programs (Fullan, 1982). What is particularly valuable is how the two mediating processes of enactment and reflection were found to be useful in connecting not only knowledge to practice but that of beliefs and practice too (Cobb, Wood & Yachel, 1990). In the process, teachers are seen as "reflective practioners" (Schon, 1983) enacting and reflecting in their practice. For instance, Teacher G's own observation of the limitations of questioning in a whole class context led him to try out small group questioning. After he saw how the small group questioning helped him better uncover students' misconceptions, his belief in small group questioning was reinforced and he continued to use small group questioning in subsequent lessons. This is consistent with the process of change described by Guskey (1986) where changes in teachers' classroom practice leading to changes in student outcomes can change teachers' beliefs.

Besides gleaning insights into the relationship between teachers' knowledge, belief and practice in the learning process, the other noteworthy point is how the teachers participated and learned in the social setting of the workshop and post lessons discussion with other teachers. This has also contributed to the understanding of how teachers' learn individually and with others at the workshop and post lesson discussion have afforded teacher's learning. Teacher J highlighted the role of both learning individually and with others in her learning process.

It is also interesting to note that some change sequences depict on-going teacher growth without the direct influence of the workshop. This is evident through the change sequences 3a-c and 4a-b (Teacher G), 3a-d (Teacher J) and 2a-c (Teachers A and Y). This shows that teachers can engage and reflect in ongoing professional experimentation and practice; and hence how teacher professional development can be reconceptualised as opportunities for learning that are embedded into the teachers' sharing routines in schools.

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In summary, I have identified evidence of teachers' initial learning through how teachers enacted and reflected on Chin's (2007) framework of questioning approaches (Socratic questioning, verbal jigsaw, semantic tapestry or framing) to promote higher-order scientific discourse in different contexts of inquiry activities, from the workshop sessions to the lesson conduct to the post lesson discussions. Through analysing and comparing the evidence of learning of the four teachers presented in the four case studies, I have uncovered seven types of change sequences and three growth network patterns across lessons using the interconnected model of teacher professional growth (Clarke and Hollingsworth, 2002). The change sequences and growth networks not only showed the relationships between the personal domain (teacher knowledge and beliefs); domain of practice (professional experimentation); domain of consequence (salient outcomes) in relation to the external domain (sources of information or stimulus) but how the changes and growth came about through enactment and reflection. This has also highlighted teachers' active roles in their own learning process, interacting with their learning experiences. These findings on how teachers learn and initiate changes in their practice suggest the importance of providing flexibility in the learning process and also opportunities for teachers to reflect on their own learning experiences so that they are more aware of how they learn and take charge of their own learning.

Chapter 5

Discussion and Conclusion

In this study, I observed and analysed how four teachers learned and collaborated on teacher questioning through a series of learning experiences designed as part of a school-based professional development model (Section 5.1) - from discussing and reflecting using Chin's (2007) questioning framework and videos of teaching and learning at a questioning workshop; to developing and applying knowledge and skills by enacting questioning in practice through lesson design and conduct for four different topics and contexts of inquiry activities; and reflecting on lesson design and use of questioning in promoting higher level student thinking in scientific discourse.

This chapter discusses how teachers learn and collaborate in using the questioning framework of Chin (2007) to promote higher-order scientific discourse (Section 5.1.1); as well as how the model of Clarke and Hollingsworth (2002) was used as a tool for analysing the process of teacher enactment and reflection as learners in questioning – its values and limitations (Section 5.1.2). It also draws conclusions on features of school-based professional development (Section 5.2) and proposes implications for curriculum developers and school practitioners on the design of professional development for teachers in questioning to support science teaching and learning (Section 5.3). The chapter ends with how this study contributes to knowledge of teacher learning and professional development (Section 5.4); as well as the limitations of the study and implications for future research (Section 5.5).

5.1 Design of a professional development model for teacher learning and collaboration on questioning

Using the principles of learning and an original framework of learning and collaboration (Figure 3), a professional development model comprising three phases of 13 learning experiences (individually and with other teachers) was developed. In the first phase, teachers' knowledge and beliefs on teacher questioning were engaged through discussion and reflection using questioning typologies and videos of teaching and learning as learning stimuli.

In the second phase, teachers were provided with opportunities to develop and apply knowledge and skills by enacting questioning in practice through lesson design and conduct of sixteen lessons in four topics and different contexts of inquiry activities.

In the third phase, teachers reflected on lesson design and use of questioning in promoting higher-order scientific discourse. The model is presented in Table 3. Teachers' learning experiences across the three phases should not be seen as sequential but a continual process of learning, where teachers go through cycles of enactment and reflection.

Table 3

Model of professional development on teacher questioning

Phase	Learning experiences
Phase one Engage teachers' knowledge and beliefs on teacher questioning through discussion and reflection using questioning typologies and videos of teaching and learning as learning stimuli	• Individual viewing of video showing teacher questioning/discussing answers from textbook • Discussion of video showing teacher questioning/discussing answers from textbook with other teachers • Individual reading of Chin's framework • Discussion of Chin's framework with other teachers • Individual viewing of videos of teaching and learning of other teachers • Discussion of videos of teaching and learning with other teachers
Phase two Develop and apply knowledge and skills by enacting questioning in practice through lesson design and conduct	• Planning of lessons with other teachers • Individual customisation of own lesson • Conducting planned lesson
Phase three Reflect on lesson design and use of questioning in promoting higher-order scientific discourse	• Individual viewing of own lesson (video) • Individual reading of own lesson (transcript) • Pair discussion of questioning and student thinking in own and other teacher's lesson (video) • Pair discussion of questioning and student thinking in own and other teacher's lesson (transcript)

The design of this model of professional development on teacher questioning is facilitated by the framework of learning and collaboration in Figure3, Chapter 3. The framework provided the focus for each phase of learning (e.g. in enacting or reflecting on questioning) and guided the design of specific learning experiences (learning experiences involving individuals or with other teachers) within each phase of learning. The next section 5.1.1 discusses how the four teachers learn through enactment and reflection with other teachers in the specific learning experiences in the model of professional development on teacher questioning (in Table 3) from the three phases in the framework of learning and collaboration (in Figure 3).

5.1.1 How teachers learn and collaborate in using the questioning framework of Chin (2007) to promote higher order scientific discourse

Since Chin (2007) developed the questioning framework based on the types and features of questioning practices of six teachers from four secondary science schools in Singapore, this is the first study reporting how teachers have learned and collaborated in using the framework to initiate changes in questioning practices at the primary level in Singapore. Teachers were found to learn and collaborate in the following areas in relation to the framework for learning and collaboration in teacher questioning in Figure 3 of Chapter 3.

- Individual learning and discussion with other teachers to understand the structure and features of Chin's (2007) questioning approaches
- Planning with other teachers and customising / enacting Chin's (2007) questioning approaches individually in different contexts of inquiry activities with other teachers
- Reflecting individually and with other teachers on the use of the questioning approaches to facilitate higher-order scientific discourse

*5.1.1.1 Individual learning and discussion with other teachers to understand the
structure and features of Chin's (2007) questioning approaches*

In this study, I observed how teachers learned and collaborated in
understanding a new questioning framework. After teachers were first introduced
to Chin's (2007) questioning framework through an article at the workshop, each
teacher first read a selected questioning approach individually before sharing and
discussing what they have learned about each questioning approach with other
teachers. They continue to deepen their understanding of the types and features of
the questioning approaches when analysing videos of teaching and learning /
lesson transcripts individually and discussing them at the workshop and post
lesson discussions with other teachers.

While all four teachers were introduced to a common questioning
framework at the workshop, they engaged in learning the questioning framework
in different ways. During the workshop, some teachers focused on analysing and
comparing the types and features of questioning approaches. For instance,
Teacher G observed features of the "verbal jigsaw" questioning approach such as
how teachers paused in mid-sentences instead of actually asking a question when
analysing videos of teaching and learning individually. Teacher A, on the other
hand, compared the differences between the questioning approaches such as
"Socratic questioning (pumping)" and "semantic tapestry (focusing and
zooming)" during the discussion of questioning approaches with other teachers.
Other teachers linked what they have learned to their existing knowledge and
practice during discussions. For example, Teacher Y clarified on specific
questioning approach (e.g. Socratic questioning) as she had a different prior
knowledge of what the questioning approach should be. Teacher J commented
that she was already using some of these questioning approaches in her current
practice but was not aware that such questioning approaches existed.

Beyond the workshop, I also observed how the teachers' knowledge, belief and practice in questioning changed, some resulting in change sequences and growth networks (Clarke & Hollingsworth, 2002). For instance, Teacher J's knowledge of the "framing" questioning approach deepened as she differentiated between strategies of "framing prelude" and "framing outline" using actual scientific discourses from Teacher G and her own lessons at a post lesson discussion. Teacher Y, on the other hand, shared her belief that Socratic questioning was nurturing in scaffolding students' understanding and not just merely for higher-order thinking. Her change in belief came after reflecting individually on her own practices across various lessons at post lesson discussions. Besides, Teacher G's successful experimentation with smaller group questioning encouraged him to use small group questioning in more lessons to promote greater student engagement and thinking.

Overall, teachers' individual learning and discussion of the new questioning framework with other teachers were facilitated by various learning stimuli presented from the questioning workshop to the post lesson discussions. These stimuli included Chin's (2007) questioning framework and videos of teaching and learning introduced at the workshop; stretches of scientific discourses from teachers' own lesson videos and transcripts at the post lesson discussions; as well as teachers' discussions at both the workshop sessions and post lesson discussions. The stimuli were used in different ways by individual teachers and when working with other teachers to facilitate teacher change in knowledge, belief and practice from the questioning workshop to the post lesson discussions. For example, at the questioning workshop, teachers started learning about the new questioning approaches by describing features and comparing questioning approaches, both individually and with other teachers. At the post lesson discussions, they reflected individually and with other teachers on how the features of questioning approaches and how they were used to promote higher-order scientific discourse. Teacher J highlighted the importance of "thinking through" individually before "listening to other people's ideas" for a "fuller experience", valuing both individual and learning experiences with other teachers.

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Hence, in this study, I observed how a school-based professional development which comprises learning experiences to encourage individual learning and learning with others, has promoted teacher learning of a new questioning framework.

5.1.1.2 Planning with other teachers and customising / enacting Chin's (2007) questioning approaches individually in different contexts of inquiry activities

In this study, I observed Teachers G and J planning, customising and enacting eight Primary Four lessons on heat and light; as well as another eight Primary Five lessons on plant reproduction and processes by Teachers A and Y. As I observed the four teachers planning, customising and enacting the questioning approaches in 16 lessons, I noticed that the goals of learning / objectives of lessons and student ability were key considerations in guiding them in their questioning practice. For instance, Teacher A emphasised that his focus was not on planning which questioning approach to use but how his questioning could help him achieve the objective of his lessons based on the desired student learning outcomes. This is evidence of how teachers integrated what they have learned about questioning as part of lesson planning, customising and enactment.

Besides observing teachers being guided by common considerations in lesson design, I noticed that all four teachers have chosen planning lessons with other teachers as one of the useful learning experiences in questioning. For example, Teacher A highlighted that planning with other teachers was a more useful experience compared to conducting the lesson as he just had to conduct what was planned. On the other hand, Teacher G's individual customisation of small group questioning reaffirmed his own belief that it promotes student engagement and thinking. This encouraged him to continue using small group questioning in subsequent lessons. These examples illustrate how teachers have

taken active roles in planning with other teachers and individual customising of lessons.

Over the period of study, I also observed teachers planning, customising and enacting a greater repertoire of questioning approaches in the later pairs of lessons compared to the first pair of lessons. For instance, Teachers G and J started using only the framing questioning approach in the first pair of lessons they planned and conducted but started combining the framing questioning approach with other questioning approaches (verbal jigsaw and Socratic questioning) in planning and conducting the later pairs of lessons. Teacher J highlighted that the use of other questioning approaches such as Socratic questioning (reflective toss) allowed her to better respond to her higher ability students. Teacher G also considered the conditions that supported effective questioning such as the use of smaller group questioning. These examples show that teachers have considered the what, why and how in planning with other teachers and customising Chin's framework of questioning approaches individually.

While planning, customising and enacting the questioning approaches, some teachers have used the lesson planning template introduced at the questioning workshop while others continued to use the school's lesson planning template. For instance, Teachers G and J used the lesson planning template introduced at the workshop when planning and customising all eight lessons while Teachers A and Y decided to use the schools' lesson planning template for their eight lessons. This is evidence of how teachers have incorporated what they have learned in their existing school and classroom practices. Hence, it is important to provide flexibility in learning to facilitate teachers in integrating what they have learned in their existing practices.

5.1.1.3 Reflecting individually and with other teachers on the use of the questioning approaches to facilitate higher-order scientific discourse

In this study, both individual and reflections with other teachers were designed as part of the workshop as well as post lesson discussion sessions. The teachers' self and reflections with other teachers on their prior knowledge, belief and practice on questioning at the workshop sessions as well as during the post lesson discussions were instrumental to teachers' changes and growth, as analysed in the change sequences and growth networks. The reflections at the workshop sessions centered on their prior knowledge, belief and existing practices; while those at the post lesson discussions focused on their enactment of questioning approaches and how questioning elicited higher order thinking / students' misconceptions in scientific discourse. For instance, Teacher G reflected on how he could have questioned differently to promote students' higher-order thinking during scientific discourse within each lesson. Besides reflecting on questioning in her current class like Teacher G, Teacher J also reflected on the differences in questioning practice in her previous and current Primary Four classes. Teacher Y, on the other hand, reflected on the change across lessons in her overall understanding of Socratic questioning. She saw Socratic questioning as a nurturing approach that can scaffold students' understanding, not just merely for eliciting higher-order thinking. Teacher A, as the Head of Science, reflected beyond his own classroom experimentation on how he can support other teachers through planning questions in various topics. This shows that teacher reflections occurred at different levels – reflections of practices within and across lessons, reflections of practices for students of different abilities, as well as reflections on supporting other teachers in questioning.

Over the period of study, teachers were found to reflect consistently on selected areas that they were concerned with. For instance, Teacher Y consistently reflected on how she used Socratic questioning in addressing students' misconceptions across lessons. Teacher G, on the other hand, focused on

reflecting how he could have questioned differently for higher-order thinking in his students. This shows that teachers have deep rooted beliefs which can influence their reflections which in turn determine their questioning practice.

While reflecting on questioning, teachers used both the videos and transcripts of their lessons. For instance, Teacher J highlighted the value of both video and transcript analyses in reflecting on questioning. She could relate to the context and relevance of questions when watching the video and thought more deeply when analysing the transcripts. Teacher A, on the other hand, highlighted the value of reflecting at post lesson discussions in raising his awareness in student thinking within scientific discourse. These insights of Teachers J and A have implications on how schools can organise professional learning communities in schools to facilitate sharing and reflection of teaching practice and student learning.

5.1.1.4 Teachers' overall reflection on learning experiences

When the four teachers reflected on the experiences that they have gone through in Figures 5, 11, 16 and 20, they chose the ones that have particularly helped them reflect and enact questioning; and each presented the learning experiences in a diagrammatic form to show how the learning experiences helped them in reflecting and enacting questioning in the learning process. Table 4 shows a comparison of the teachers' choices of learning experiences.

Table 4

An overview of learning experiences in questioning which teachers found useful

	Teacher G	Teacher J	Teacher A	Teacher Y
At the workshop				
• Individual viewing of video showing teacher questioning/discussing answers from textbook		*		
• Discussion of video showing teacher questioning/discussing answers from textbook with other teachers		*		
• Individual reading of Chin's framework	*	*		
• Discussion of Chin's framework with other teachers	*	*	*	*
• Individual viewing of videos of teaching and learning of other teachers	*	*	*	
• Discussion of videos of teaching and learning with other teachers	*	*	*	*
• Planning of lessons with other teachers	*	*	*	*
• Individual customisation of own lesson	*			
Lesson conduct				
• Conducting planned lesson	*	*	*	*
Post lesson discussion				
• Individual viewing of own lesson (video)	*	*	*	
• Individual reading of own lesson (transcript)	*	*	*	
• Pair discussion of questioning and student thinking in own and other teacher's lesson (video)	*		*	*
• Pair discussion of questioning and student thinking in own and other teacher's lesson (transcript)	*		*	*
Other considerations in questioning				
• Purpose of lesson	*	*		
• Specific instructional objectives in concepts and process skills		*		
• Department input		*		
• Course on critical inquiry on questioning			*	
• Student ability	*			

Comparing the four teachers' illustrations of their learning experiences in Figures 5, 11, 16 and 20 and Table 4, it was observed that different combinations of learning experiences were useful for different teachers. The teachers have highlighted between five to nine out of the thirteen learning experiences provided. Among the various learning experiences, the planning of lessons with other teachers was found to be useful by all four teachers. Some of the learning experiences were useful to three out of the four teachers while the others were useful to two of the four teachers, as seen in Table 5.

Table 5

Useful learning experiences for teachers

Useful for three of four teachers	Useful for two of four teachers
• Discussion of Chin's framework with other teachers	• Individual viewing of videos of teaching and learning of other teachers
• Discussion of videos of teaching and learning with other teachers	
	• Pair discussion of questioning and student thinking in own and other teacher's lesson video
• Conducting planned lessons	
• Individual viewing of own lesson video	• Pair discussion of questioning and student thinking in own and other teacher's lesson transcript
	• Individual reading of own lesson transcript

It is interesting to observe that while all teachers went through the same learning experiences in the same sequence, the various learning experiences helped them reflect and enact in different ways. For instance, in the teachers' illustrations of how the learning experiences were used in their reflection and enactment of questioning, the conducting of lessons was at the heart of learning for Teachers J and Y while the planning / customisation of

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lessons was the focus for Teachers A and G. Teacher A elaborated that he learned most from reflecting at post lesson discussions, compared to what he learned when conducting lessons:

> *"The thing I learn most is when I look at it and think of what I have done. The conducting is just the carrying out of lesson. To me, that one is an everyday thing. For me, reflecting on lesson discussions on what I actually pick out; how it actually aligns itself to the approaches and what are some strategies used that I am also not conscious of. I benefit the most out of the period of time". (PC)*

This has highlighted teachers' active roles in their own learning process, interacting with their learning experiences. This suggests the importance of providing flexibility in the learning process and also opportunities for teachers to reflect on their own learning experiences so that they are more aware of how they learn and take charge of their own learning.

Besides, each of the four teachers chose a combination of learning experience, comprising a mixture of individual learning and learning with other teachers. Teacher J particularly highlighted the importance of learning individually and with others at one of the post lesson discussions with Teacher G:

> *"You form your own ideas first. Then, when you listen to other people's ideas, it is always a fuller experience. But yet if you just launch straight into collaborative, without the individual, there is not much of implication and think through on your own."(PC)*

Overall, the teachers' reflection on learning is consistent with my own observation of the teachers' learning process. For instance, Teachers G and Y have highlighted explicitly their learning from Teacher J and A in their respective Primary Four and Primary Five post lesson discussions. They were also the ones who highlighted that the pair lesson discussions were useful learning experiences. Teacher G, for example, shared that he had learned about using "semantic tapestry (multi-modal thinking)" questioning approach to promote student thinking from Teacher Y. In fact, Teacher G stated his learning explicitly at this second exposure to this questioning approach

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through Teacher J's lesson but not from the day one workshop session where the questioning approach was first introduced:

> *"When I plan a lesson now, I am more aware. I will think of where I can put in a multimodal kind of. Previously, I was not aware of multi-modal. Now, I think I can put that in. That will help enrich my lesson. Like what she (Teacher J) said, the thinking process is much better. Definitely, the lesson improvement, for me is there. After the discussion, I ask myself why I did not use multi-pronged. Very good strategy to use. I am learning." (PC)*

Teacher Y, on the other hand, shared how a discussion between herself and Teacher A on a question posed by Teacher A's student prompted her own thinking.

> *"Even that question got me thinking. After his lesson, he (Teacher A) came to me and he was telling me (his) student asked this question. I was like ... wow ... that is quite high level, you know. In order to be able to see that perspective. What is fundamentally different between other living organisms and plants. Even current science may not able to answer that question." (PC)*

The above accounts of how Teachers G and Y learned from Teachers J and A respectively highlight the importance of providing multiple opportunities for teacher learning. Learning can also occur in informal settings such as how Teachers A and Y continued their discussion beyond the structured post lesson discussions.

While this model of professional development on teacher questioning was found useful to support Teachers G, J, A and Y in learning individually and with other teachers, the model may have to be customised to include other learning experiences for other teachers in this school or other schools. The current learning experiences may have to be sequenced differently too. While customising the specific learning experiences, the framework of learning and collaboration would serve as a useful frame for designing specific teachers' learning experiences.

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5.1.1.5 Reflection on my roles as curriculum specialist and researcher

In this study, I played dual roles as a curriculum specialist and a researcher. To support teachers as a curriculum specialist, I conducted workshops and participated in lesson planning and discussion focusing on questioning to promote higher-order scientific discourse. My role was supportive in nature, mainly to ask questions to elicit teachers' prior knowledge and experiences; as well as facilitate their enactment and reflection of questioning. While I let teachers take the lead in learning through planning, enacting and reflecting on lessons, teachers' responses might be affected by how they perceived my role as a curriculum specialist from the Ministry of Education. The questions that I asked might also have influenced what, how and when teachers learned to some extent.

As a researcher, I wanted to understand the processes of teacher learning and collaboration when they were initiated into a professional development programme. At the workshop, I analysed how learning stimuli, such as videos of teaching and learning and Chin's (2007) questioning framework, helped teachers to reflect on their knowledge and experience to discuss questioning approaches and student thinking. Beyond the workshop, I analysed how teachers applied the questioning framework in professional experimentation (planning and enacting questioning approaches). At the post lesson discussions, I not only analysed how teachers reflected on questioning approaches and student learning; I also analysed how teachers reflected on students' salient learning outcomes. As I only joined teachers for selected lessons and post lesson discussions, my interpretations were limited to observations on how teachers were initiated into enacting and reflecting questioning within these learning experiences only.

Having played dual roles as a curriculum specialist and a researcher, I recognise that both roles are closely intertwined in practice. As a curriculum specialist, how I organised the learning experiences within the professional development programme has scoped the boundaries for my analysis and interpretation of teachers' learning across the planned learning experiences.

The analysis, in turn, informed the ongoing modification and future design of the professional development programme.

5.1.2 Analysing teachers' changes and growth through their reflection and enactment using the model of Clarke and Hollingsworth (2002)

The interconnected model of Clarke and Hollingsworth (2002) was useful for analysing and presenting change sequences and growth network in the four domains: the personal domain, K (teacher knowledge and beliefs), the domain of practice, P (professional experimentation), the domain of consequences, S (salient outcomes), and the external domain, E (sources of information, or stimulus). The mediating processes of enactment and reflection represented in the model as arrows linking the domains can show how the domain changes come about in a non-linear fashion, not just the relationships between the four domains. While using the model to analyse teachers' change sequences and growth networks, I have gained insights into the value and limitations of the model as an analytical tool.

5.1.2.1 Value of the interconnected model by Clarke and Hollingsworth (2002)

The model has been useful in analysing the evidence of learning and change sequence / growth network of the four teachers G, J, A and Y, particularly on how they enacted and reflected on Chin's (2007) questioning framework at the workshop sessions, lesson conduct and post lesson discussions presented. I could study in depth, how they initiated their learning with other teachers in the real-life contexts of the school and classrooms.

Firstly, I could identify the various learning stimuli within the external domain. These include Chin's (2007) questioning framework and videos of teaching and learning introduced at the workshop; stretches of scientific discourses from teachers' own lesson videos and transcripts at the post lesson

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discussions; as well as teachers' discussions at both the workshop sessions and post lesson discussions. Using the interconnected model, I could trace and understand how the stimuli led to teachers' change sequences and / or growth networks for teachers' learning and plan for learning stimuli in future professional development.

Secondly, the model could capture the multidimensional nature of teacher learning. I could use the model to analyse how the various stimuli at the workshop and post lesson discussion platforms (external domain) brought about changes in the other domains including the personal domain (knowledge and belief in questioning), domain of practice (experimentation with Chin's questioning framework) and domain of consequence (student learning and thinking in scientific discourse). Teachers' initial changes in practice included refinements / extensions rather than fundamental changes of their questioning practices. This shows the importance of considering teachers' existing knowledge, belief and practice in introducing new pedagogical approaches.

Thirdly, as the four domains (external domain, personal domain, domain of practice and domain of consequence) are linked by the mediating processes of enactment and reflection in the model, I could use the model to analyse teachers' change and growth across the four interconnected domains, beyond the workshop platform and across lessons. Some of the teachers' change sequences are similar but the overall growth networks for different teachers are different. This shows that the interconnected, non-linear structure of the model enabled the identification of different individual sequences and growth networks, recognising the idiosyncratic and individual nature of teacher professional growth. Hence, in designing professional development, it is important to incorporate flexibility as teachers enact and reflect differently and hence learn through different pathways. This responsive approach to professional development is aligned to the suggestion by Clarke and Hollingsworth (2002) to deliberately design programs to provide teachers with the opportunity to enact change in a variety of forms and change sequences consistent with individual inclinations.

5.1.2.2 Limitations of the interconnected model by Clarke and Hollingsworth (2002)

While the model allows the identification of change domains as well as mediating processes of enactment and reflection; and possible relationships between the external domain, personal domain, domain of practice and domain of consequence, the model captures the broad changes that happen over time but not the progression of individuals before there is evidence of change. Besides, while teacher change can be represented by one or more change sequences, the possible interactions between the change sequences may not be explicitly represented in the model.

Hence, to fully understand teacher changes / growth and the implications for designing future professional development, it is worthwhile to invite teachers themselves to provide their own perspectives on how the various learning experiences have helped them in reflecting and enacting practices. It is also recommended that the model of change / growth be presented with detailed case descriptions such as those presented in this study so that significant moments of teacher reflection and enactments which may not be captured as overall change in the model can also be featured.

Overall, the interconnected model of teacher professional growth by Clarke and Hollingsworth (2002) is a promising tool in analysing teachers' change and growth both in and out of the classroom individually and with other teachers. It provides insights into whether and how change in one domain has led to changes in other domains and how the domains are connected. The analysis of teachers' change and growth is in turn useful in informing teacher learning and the design of professional development for teachers.

5.2 Features of school-based professional development

Working with teachers to understand the process of how they learn and collaborate in the school context has helped to identify useful features of school-based teacher professional development. In future design of school-based teacher professional development, the following features can be considered:

- Providing a variety of stimuli for learning at different parts of teachers' learning journey
- Providing opportunities for both individual and learning with other teachers
- Engaging learners in reflecting on learning experiences
- Providing scaffolding for reflection
- Providing flexibility for teachers in their learning journey

5.2.1 Providing a variety of stimuli for learning at different parts of learning journey

In this study, various stimuli were used in the process of teachers' learning. Chin's (2007) questioning framework was one of the stimuli which provided a common language for teachers to discuss, enact and reflect on questioning. The use of the framework as a common language was evident when comparing how teachers analysed questioning practices in video cases before and after the introduction of Chin's (2007) questioning framework at the workshop platform. After the introduction of the questioning framework, teachers could identify the specific questioning approaches and strategies; describe their features and how they were used in different context of inquiry activities. For instance, before the introduction of Chin's (2007) framework of questioning approaches, Teacher J described the broad purpose of questions. After the introduction of the framework, Teacher J named the questioning approaches and cited specific scientific discourse from the video case.

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Besides Chin's (2007) questioning framework, the teachers' own and other teachers' video cases of classroom practices also provided stimuli for teachers to discuss and reflect on how Chin's (2007) framework of four types of questioning approaches were used in authentic contexts of different topics and lesson contexts at both the workshop and post lesson discussions. In addition to the video cases, teachers also found the lesson transcripts of self and others useful stimuli for reflection on questioning practices. Teacher J highlighted the value of both video and transcript analyses – she could relate to the context and relevance of questions when watching the video and thought more deeply when analysing the transcripts.

At the end of the learning journey, when reflecting on useful learning experiences, Teachers G, J and A highlighted that the individual viewing of video cases was beneficial while Teachers G and Y found the pair viewing / discussion of video cases useful. This finding on the value of individual video viewing supported some of the findings of Seidel et al. (2011). Seidel et al. (2011) compared the effects of analysing videos of one's own versus others' and reported that teachers who analysed their own teaching experienced higher activation – higher immersion, resonance and motivation. While I found the four teachers reflecting more on their own video cases especially at the beginning of the post lesson discussions, I also observed teachers participating in each other's video cases on specific observations or findings when they discussed lessons which they have planned with other teachers and customised / conducted individually. For instance, Teachers G and J compared how the different everyday contexts that each of them customised in their respective lessons provided students with opportunities of higher-order scientific discourse in the lessons on heat conduction.

The findings from this study suggest that it is useful to include a variety of stimuli in different parts of the school-based teacher professional development journey. It is also important to choose stimuli which teachers can relate to such as teachers' own lessons and present the stimuli in different formats (video or text) to cater to teachers' different learning needs. In addition, the use of stimuli at regular platforms can encourage teacher reflection (Schon, 1983) and talk about science teaching and learning (Pedder,

James & MacBeath, 2005) using specific scientific discourse from teachers' own classrooms.

5.2.2 Providing opportunities for learning individually and with others

In each of the learning experiences planned in this study, opportunities were provided for teachers to learn on their own and in pairs (within the Primary Four or Primary Five level at post lesson discussion sessions) or groups of four (across Primary Four and Five levels at workshop discussion sessions). These learning experiences were provided at different stages of teachers' learning journey; at the workshop discussion and during the post lesson discussion sessions. For instance, during the workshop, teachers individually read one of Chin's (2007) questioning approaches before discussing the four questioning approaches with other teachers. Teachers had the opportunity to explain their own understanding of the questioning approach that they read and also discuss the questioning approaches that the other teachers presented. At the post lesson discussions, each teacher first identified parts of his / her lessons and reflected on the use of questions to promote scientific discourse before learning from each other's practices. The individual reflections and discussions with other teachers at both the workshops and post lesson discussions have promoted pedagogic discourse, largely centered on the use of questions to promote scientific discourse in different topics and lesson contexts for different students.

At the end of the learning journey, when asked to choose the learning experiences which helped them learn, each of the four teachers chose a different combination of learning experiences. Within each combination of learning experiences that each teacher chose, different learning experiences involving the individual as well as other teachers were included. This shows that teachers valued learning opportunities for individual and with other teachers though each teacher had different preferences for different combinations of learning experiences. Teacher J highlighted the importance of learning experiences for the individual as well as with other teachers so that

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there is "thinking through" individually before "listening to other people's ideas" for a "fuller experience". The analysis of teachers' individual reflections and discussions with other teachers at the workshop and post lesson discussions revealed that some individual reflections remained as individual comments while others prompted further discussions with other teachers. Among the discussions which focused mainly on questioning goals, approaches, practices and / or student thinking, some discussions were more in-depth discussions while others were merely short exchanges of views. Among the more in-depth discussions, a comparison showed that the teachers talked about selected aspects of lessons which they planned together but enacted differently (e.g. discussion of how the framing questioning approach was used differently by Teachers G and J; discussion of student thinking (creating) between two lessons on "role-play of plant sexual reproduction" and "making connections between plant processes" by Teachers A and Y). Some of these more in-depth discussions were found in the earlier post lesson discussions of Teachers G and J, compared to Teachers A and Y. This is consistent with my observations of Teachers G and J who were more forthcoming in sharing their reflections. They were also more reflective in their own practices and articulated the need to change right from the first pair of post lesson discussions. Hence, the staging of the post lesson discussion lent itself to the building of collaborations, providing opportunities for sharing reflections on their learning but some teachers may need more scaffolding and time to engage in more productive collaborations.

This study has provided insights into how teachers have learned individually and with others at and beyond a workshop platform in the context of their school environment. In designing school-based professional development, it is useful to incorporate individual reflection routine and post lesson discussion with other teachers to promote ongoing pedagogical discourse grounded in empirical evidence from teachers' own classroom practices. Pollard (2010) also highlighted pedagogical discourse as fundamental to teachers' sense of professional identity, grounded not only in empirical evidence but also in ideas, theories and ethical values. Besides the use of pedagogic discourse, Turner and Simon (2012) also highlighted the

importance of teachers in scrutinising policy and practice in reference to theory. In doing so, teachers not only develop a strong sense of professional identity but also increased confidence. This suggestion by Turner and Simon (2012) would be especially relevant when a new syllabus, pedagogy approach or assessment mode is implemented – it is important to engage teachers in individually reflecting and discussion with other teachers on how the new syllabus, pedagogy approach or assessment mode can be effectively implemented or integrated into their own practice to support student learning.

5.2.3 Engaging learners in reflecting on learning experiences

Teacher reflection was designed not only as part of the workshop learning experience but during the post lesson discussions across a total of 16 lessons from four topics in the Singapore primary science syllabus. In both the workshop and post lesson discussions, teachers were provided with opportunities to reflect on the four domains in Clarke and Hollingsworth's (2002) interconnected model of teacher professional growth. Teachers reflected on their knowledge and belief (personal domain) in questioning and scientific discourse using their own and other teachers' science lessons (external domain). They also reflected on the enactment of Chin's (2007) questioning approaches and strategies (domain of practice) in promoting higher-order scientific discourse (domain of consequence) at post lesson discussions.

At the end of the learning journey, in order to better understand teachers' process of learning, each teacher was asked to identify the learning experiences that have helped him / her learn and use questioning to promote higher-order discourse in his / her science classes. Each teacher was also asked to relate in a diagram how each of them saw the connections between the various learning experiences – whether they helped them in reflecting or enacting in their process of learning. A comparison of the four teachers' illustrations of learning process allowed us to gain insights into how the workshop and post lesson experiences were stimuli in their reflection and

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discussion of questioning and scientific discourse in various topics and contexts of lessons. Besides, as teachers also reflected on their personal considerations in customising and conducting lessons, we also have insights into teachers' other considerations that guided them in enacting and reflecting on questioning. For instance, Teacher G highlighted "purpose of lesson" and "student ability" in his illustration; Teacher J included "specific instructional objectives" and "department input" in hers; while Teacher A incorporated a course he attended on "critical inquiry on questioning" in his.

Hence, based on teachers' reflections on their overall learning journey, we observed how four teachers experienced the same three phases of 13 learning experiences but played active roles in their own learning process, interacting with their learning experiences. This kind of learning has the features of transformative learning (Kennedy, 2005) where teachers are active participants, shaping their own development through reflective participation (Clarke and Hollingsworth, 2002). This suggests the importance of providing opportunities for teachers to reflect on their own learning experiences so that they are more metacognitive about what they know, how they know it and what they do (Capps, Crawford and Constas, 2012).

5.2.4 Providing scaffolding for reflection

In this study, teachers were scaffolded in reflecting at different parts of their learning journey, during the workshop sessions and post lesson discussions. During the workshop reflection, scaffolding was provided through a workshop journal template. The template contained open-ended question prompts and headers to prompt teachers on areas to think about (e.g. types of questions, purpose of questions) and express their reflections. After each teacher wrote down individual reflections, they also had opportunity to share their reflections with other teachers. The teachers' reflections were in turn scaffolds for subsequent reflections. Besides, postcards were provided at the third day of workshop to prompt teachers' reflection on their learning process and experiences. At post lesson discussions, a simple template was also

provided to facilitate teachers' in reflecting individually (e.g. questioning approaches which helped in promoting students' higher order thinking in scientific discourse) and highlighting sections of their video lessons for discussion. The Revised Bloom's taxonomy (Forehand, 2005) was also used to support teachers in reflecting on students' level of thinking within scientific discourse.

At the end of the learning journey, when reflecting on useful learning experiences, three out of the four teachers found it useful to have reflections with other teachers on Chin's (2007) questioning framework and examples of teaching and learning used during the workshop sessions. Similarly, two out of the four teachers also found the reflections using video cases of each other's lessons useful at the post lesson discussions with other teachers. While teachers found the reflection sessions useful, the teachers were observed to need more prompting during the initial post lesson discussions as compared to the later ones. Besides, in the initial workshop discussions, teachers' reflections focused more on the questioning approaches used (the domain of practice). In the post lesson discussions, teachers' reflections also included how the questioning approaches can be changed to enhance student thinking within scientific discourse (the domain of consequences). The findings from this study are similar to what Sherin and Han (2004) found in mathematics teachers' discussions where teachers became increasingly focused upon examining student thinking rather than their own pedagogy.

Hence, while this study has affirmed the value of teachers sharing reflections on their questioning practice and student thinking in scientific discourse; it has also highlighted that teachers need scaffolding in making more meaningful reflections and discussions. These findings highlight the importance of structuring ongoing reflection opportunities for teachers to think about their own teaching practice and student learning beyond "one-off" workshops which teachers attend currently. It is also important to plan scaffolding structures to support teacher reflection within and beyond the workshops.

5.2.5 Providing flexibility for teachers in their learning journey

For this study, teachers experienced a common school-based professional development comprising three phases of 13 key learning experiences but they were provided with choices during their learning journey. For instance, from the introduction of Chin's (2007) framework during the workshop, each teacher could choose the questioning approach of interest to focus on learning first though they had the opportunity to learn about all questioning approaches from each other eventually. During lesson planning, each pair of teachers chose the topics and lessons as well as the questioning approach or approaches to focus on. Each teacher also decided how to customise each lesson, including how to use questions to scaffold student learning and thinking in scientific discourse. At post lesson reflection and discussion, each teacher could select specific sections from their own video lessons and transcripts to reflect on and discuss.

Besides providing teachers with flexibility and choice during the learning journey, I was also interested to find out from the teachers' own reflections on how the various learning experiences actually supported them flexibly in enacting and reflecting on Chin's (2007) questioning framework. Hence, each teacher was asked to reflect through a diagram on how the various learning experiences helped in the process of learning. An analysis of the diagrams presented by the four teachers showed that teachers have interacted or responded to the different learning experiences in different ways. For instance, Teachers J and Y related how the various learning experiences supported them in conducting their lessons while Teacher A and G found the learning experiences useful in planning their lessons.

From this study, teachers were provided with flexibility in learning at different levels. Firstly, flexibility was incorporated into the design of each learning experience such as providing teachers with flexibility on what to learn, enact and reflect. Secondly, flexibility was also provided in how they use the learning experiences such as in planning or conducting their lessons. The findings from this study highlight the importance of providing flexibility

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and choice for teachers in their learning journey. It is also valuable to engage teachers to reflect on their own learning journey so that they are more aware of their own learning and can better customise the learning experiences to serve their own learning needs.

5.3 Implications for school practitioners

The findings on how teachers learn and collaborate in enacting and reflecting on questioning to promote scientific discourse have implications for school practitioners in designing school-based professional development for teachers. Schools are increasingly identifying teachers' needs and initiating school-based programmes of professional development. With the establishment of the Academy of Singapore Teachers in 2010, one of the aims is to foster pedagogical leadership focused on teacher collaboration in learning communities within and beyond schools in professional networks. It also aims to strengthen the culture of teaching excellence and raise the standards of practice in the classroom and across Singapore's education system.

The findings of my study suggest when and how teachers can be provided with opportunities to plan, reflect and discuss their practices with other teachers in on-going and regular professional development. This can be in learning communities within and / or across schools. In such communities of practice, Simon, Campbell, Johnson and Stylianidou (2011) highlighted that an agenda for change should be part of the community of practice with a shared vision and commitment to changes, rather than dictated from the schools' senior management. The effectiveness of the professional development is related to school cultural practices as well as processes for development within science departments including supportive systems and structures.

All these findings have implications on the roles of school leaders, middle managers and teachers in school-based professional development. Besides consulting teachers, establishing a shared vision and systematic plan for teacher on-going development, school leaders need to provide a conducive

school context for every stage of the professional development process - from accessing opportunities for professional development, to support for participation, encouragement to experiment with new teaching techniques and support in application of new ideas. Clarke and Hollingsworth (2002) cautioned that the school context can impinge on a teacher's professional growth at every stage of the professional development above. Hence, in future syllabus implementation, I can facilitate planning and initiation sessions for science key personnel from different schools. At these sessions, they can start conversations and exchange ideas on plans for supporting teacher development and syllabus implementation within and across schools.

5.4 Contribution to theory and practice of teacher learning and professional development

As presented in Chapter two earlier, Darling-Hammond and Bransford (2005) highlighted that there is a lack of research in how teacher learning affects teaching practices / student outcomes as well as how teachers learn successful practices, probably due to the complexity of teacher learning and practice. My study has provided insights into these aspects of teacher learning and practice in a school-based professional development embedded in the social setting of a primary school, particularly on teacher learning and collaboration in using questioning to promote higher-order scientific discourse. What is noteworthy is the provision of empirical evidence on teachers' learning, connecting teachers' participation in the school-based professional development with desired outcomes such as changes in knowledge, beliefs and practice through change sequences and growth networks using the interconnected model of Clarke and Hollingsworth (2002). Such empirical literature is found to be lacking in a recent review by Capps, Crawford and Constas (2012) on inquiry professional development.

Overall, this study has not only contributed to empirical literature on inquiry professional development in the area of teacher questioning but also to

theory and practice in teacher learning and professional development in the following areas:

- Development of school-based professional development on teacher questioning
- Understanding of teacher learning as collaborative and reflective
- Contribution to the use of interconnected model as an analytical tool of teacher learning and collaboration in questioning

5.4.1 Development of school-based professional development on teacher questioning

One of the contributions of my study is the development of an original framework for learning and collaborating in teacher questioning to guide the design of learning experiences (Chapter 3, Figure 3); a school-based teacher professional development model comprising 13 learning experiences (Chapter 5, Table 3); and the identification of features which supported teachers' learning and use of questioning. So far, studies have reported more of features of effective inquiry professional development on science in general. One of the recent reviews of empirical studies on inquiry professional development for science teachers by Capps, Crawford and Constas (2012) identified common features of effective inquiry professional development. Some of these features include the provision of extended support beyond a professional development workshop, provision of time for reflection and discussion on how to enact or transfer experiences in classrooms. These features are also found to be important in my study which focuses on professional development on teacher questioning. In addition, other key features which have been found to be important include providing a variety of stimuli for learning at different parts of teachers' learning journey as well as opportunities for both learning individually and with other teachers.

To successfully incorporate the above mentioned features of professional development, I have observed the importance of having an open

sharing culture and structured time for teacher professional development while working with the four teachers in this study. Similarly, Simon, Campbell, Johnson and Stylianidou (2011) suggested promoting teachers as part of a community of learners as well as including time for peer observations and shared practices. Findings from Simon et al.'s and my study are aligned to some of the conditions identified by Hoban (2002) which are important for teacher learning and situated in teachers' own school and classroom contexts. The implication for schools would be to consider some of the useful features surfaced from this study in the design of their own school-based professional development and also identify the unique conditions that not only support teachers in learning but also sustain change and practice in their own school contexts.

5.4.2 Understanding of teacher learning as collaborative and reflective

This study has also contributed to the understanding of teacher learning as collaborative and reflective – how teachers learned Chin's (2007) questioning framework with other teachers in the social setting of their school and classrooms through enactment and reflection on the use of the questioning approaches to promote higher-order scientific discourse.

In terms of teachers as collaborative learners, this study shows how learning with others can be "planned learning" (Hodkinson & Hodkinson, 2005), structured as part of teachers' ongoing school-based professional development to initiate change in questioning practice. Common platforms at the workshop and post lesson discussions have provided opportunities for reflection and discussion of a new questioning framework as well as planning and reflection of lessons with other teachers. Such conversation and discussion, observing and taking interest in what others do and joint activity are reported to be important by Hodkinson and Hodkinson (2005) too. What is also valuable is the empirical data on what and how teachers work with other teachers beyond the workshop in enacting lessons, as well as in post lesson

reflection of their questioning practice and scientific discourse. The nature of collaboration in this study has characteristics of "collaborative culture" (Hargreaves, 1994) as teachers were spontaneous and took initiative in sharing reflections and resources in informal setting beyond the scheduled workshop and post lesson discussions. The collaborations were also developmental in nature. The evidence of teachers' collaboration could also be explicitly captured as part of their change sequences and growth networks using the interconnected growth model of Clarke and Hollingsworth (2002). These collaborative practices can potentially be presented as vignettes of questioning practices to inform professional development of other teachers.

This study has also contributed to the understanding of teachers as reflective practitioners (Schon, 1983), particularly on how they were active learners shaping their own change and growth in questioning through reflective participation (Clarke and Hollingsworth, 2002). Teachers' reflective participation in this study was initiated and facilitated largely through interaction with teachers' ideas on the new questioning framework and reflections at both the workshop discussions and post lesson discussions. The reflective practices observed in this study can be described as critical reflection where teachers focused on their practices and perspectives, looking at their lessons from various topics to reflect on their practices. Turner and Simon (2012) described critical reflection as looking long (looking back at accepted routines) and looking wide (looking at wider socio-political contexts). In this study, I observed more of looking long, focusing more on the reflection of specifics of classroom practices – reflections of practices within and across lessons, reflections of practices across students of different abilities, as well as reflections on supporting other teachers within the school in questioning. Besides, I also observed that teachers reflected consistently on selected classroom practices, including questioning for better engagement and thinking (Teacher G, Teacher J), questioning for uncovering misconceptions (Teacher Y) as well as questioning for achieving lesson objectives and student outcomes (Teacher A). This shows that teachers have deep rooted beliefs which can influence their reflections which in turn determine their questioning practice. This consistency in teaching practice was also observed by Simon,

Erduran and Osborne (2006) in their study of teachers learning to teach argumentation. These findings suggest the importance of engaging teachers in reflecting on their knowledge, belief and practice as well as their own learning experiences.

Besides encouraging individual teachers to be more metacognitive about what they know, how they know it and what they do (Capps, Crawford and Constas, 2012), Shulman and Shulman (2004) also highlighted the value of shared meta-cognitive reflection where teachers critically discuss and reflect on their questioning approaches and student thinking with each other. Regardless of whether it is reflection individually or with other teachers, I have observed the need for scaffolding teachers in reflecting on their practice as they do not necessarily have adequate guidance as to how and when to reflect, also highlighted by Simon, Campbell, Johnson and Stylianidou (2011). From my study, the use of teachers' own video lessons and lesson transcripts helped to focus reflection whilst still providing flexibility and choice in the area of reflection. Simple templates with question prompts were also found to be useful in guiding teachers on how and when to reflect. These findings highlight the importance of supporting teachers' reflection individually and with others as part of teachers' learning while still providing them with the flexibility of identifying the focus of reflection.

5.4.3 Use of interconnected model as an analytical tool of teacher learning and collaboration in questioning

This study has shown how the interconnected model of Clarke and Hollingsworth (2002) can be used as analytical tool for teacher learning and collaboration in questioning. I was able to identify the key change domains (personal domain, domain of practice, domain of consequence, external domain) and mediating processes (enactment and reflection) as well as the possible relationships between the domains presented in change sequences and growth networks. Findings not only reveal similar change sequences reported

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by Clarke and Hollingsworth (2002) but also four new change sequences based on empirical evidence from this study. These new change sequences have also contributed to three distinct growth networks for the four teachers. Hence, this study has provided further empirical evidence to illustrate how the interconnected model of Clarke and Hollingsworth (2002) could be used as an analytical tool in the area of teacher learning and collaboration on questioning.

The analysis of the empirical evidence using the interconnected model has also provided insights into different types of changes which were initiated in teachers' questioning practices. The changes from the different domains could be identified through teachers' enactment as well as reflections of their questioning practices. For instance, examples of changes in the personal domain include Teacher Y's knowledge / understanding of a specific questioning approach on Socratic questioning; and Teacher A's belief in the value of planning questions as part of lesson design for other topics to support other teachers. Changes in the domain of practice were also noticed in Teacher G's use of small group questioning upon his own reflection on the need to better engage his students; as well Teacher J's use of questioning with role play which she was introduced to at the workshop.

Besides analysing the changes initiated in the teachers' questioning practices, the analysis and comparison of the change sequences and growth networks of the four teachers also reveal that the teachers' engagement in pedagogic discourse at the workshop / post lesson discussion platforms in pairs or groups was instrumental to the subsequent enactments and reflections leading to the change sequences and growth networks. This could be due to the explicit grounding of the pedagogic discourse on ideas and empirical evidence as pointed out by Pollard (2010). In this study, the pedagogic discourse was focused on the specifics of classroom practice, including talk on types and features of questioning approaches as well as student responses and thinking in scientific discourse with other teachers. Pedder et al. (2005) are also of the view that teacher learning can be deepened through talk about teaching and learning. In my study, the talk on teaching and learning was facilitated by teachers collaborating in reflecting and discussing their own classroom practices. For instance, Teacher J and G discussed at a post lesson

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discussion on using questions to inculcate values of cooperation when collecting experimental data. Their discussion with other teachers became a source of input in the external domain for Teacher G and subsequently bringing about changes in the other domains (personal domain, domain of practice and domain of consequence). Teacher G continued to use questions to promote student cooperation in subsequent lessons. Hence, the study has provided insights on how the model can be a potential tool to analyse how teachers collaborate through pedagogic discourse in their learning process. This can be seen as a contribution to the development of the model as it has so far been used mainly for analysis of individual teacher change and growth.

5.5 Limitations of study and implications for future research

Firstly, the aim of this study was to explore how teachers learn and collaborate to initiate changes in questioning practice to promote higher-order scientific discourse. In future studies, researchers and educators can further explore factors or conditions in the school environment that sustain or extend teachers' initial changes and learning of questioning. Besides focusing on teachers' learning, it is also worthwhile to examine the roles of the curriculum developers in the process of initiating or sustaining teachers' learning. If the curriculum developers are playing dual roles of curriculum developers cum researchers, it will also be important to recognise that the roles of the curriculum developers can affect their interpretations of how teachers were initiated into a professional development programme focusing on questioning to promote higher-order scientific discourse. Such research provides useful insights not only on how curriculum developers can influence teacher learning but what they can interpret about teaching learning while supporting teachers in the curriculum implementation process.

Secondly, besides exploring how teacher learning was initiated, this study focused on studying teachers' questions and student thinking within scientific discourse identified by teachers in post lesson discussions. The

analysis of students' thinking was based on individual student's utterances or responses to teachers' questions but not from other evidences of student learning such as through the written work. Besides, the relationship with students' science achievement scores was not explored. This could be a focus for future studies but it is important to recognise that students' achievement would be attributed to other instructional strategies or practices, not just teachers' questioning.

Finally, this study of four teachers through a multiple-case study approach, was a modified case study approach that is scoped to focus on how they were initiated in enacting and reflecting on their knowledge, belief and practice in questioning with other colleagues; starting from the teacher questioning workshop in their own school setting. It would be worthwhile to gather further background information on teacher participants in future studies to explore if their educational background or teaching experiences may have influenced how they have learned, enacted and reflected on their classroom practices. Besides, the findings were based on four teacher volunteers and should not be generalised to other teachers who may have different educational background and teaching experiences. It would also be worthwhile to explore how this school-based professional development model can be applied in other lesson contexts and scaled up across levels involving more teachers; as well as in more schools with teachers with different profiles and experiences.

Concluding remarks

The purpose of this study was to understand how teachers learn and collaborate when a professional development programme is undertaken to inform the design of school-based professional development on teacher questioning. An original framework of teacher learning and collaboration in teacher questioning designed based on the principles of how people learn was useful in guiding the design of the school-based professional development

comprising learning experiences for the individual and with other teachers. The interconnected model of teacher professional growth by Clarke and Hollingsworth (2002) was useful in analysing and understanding teachers' learning in terms of change and growth, providing insights into the complexity of and differences in teachers' learning of a new questioning framework by Chin (2007) from the workshop participation to lesson enactment to post lesson discussions. Besides using the model to identify the interconnections of individual teacher's personal knowledge, belief, professional practice and salient outcomes, this study has contributed to the development of the model of Clarke and Hollingsworth (2002) by using it to understand how teachers enact and reflect with other teachers in the learning process. Overall, the study has also contributed to the understanding of teacher learning as reflective and collaborative in the area of questioning. The empirical findings of how teachers learn individually and with other teachers in an authentic school setting were particularly valuable in understanding the complexity of teachers' learning and practices in questioning. These findings have made a significant contribution in informing the design of teacher professional development in questioning, an important feature of science inquiry in the 21st century.

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Teacher questioning approaches by Chin (2007)

Questioning-based Approach and Strategies Used	Features	When Used
Socratic Questioning	Use a series of questions to prompt and guide student thinking	To encourage student to generate ideas based on reasoning and prior knowledge
• Pumping	Encourage students to provide more information via explicit requests	To foster student talk
• Reflective toss	Pose a question response to a prior utterance made by the student	To throw the responsibility of thinking back to the student
• Constructive challenge	Pose a question that stimulates student thinking instead of giving direct corrective feedback	To encourage student to reflect on and reconsider his answer if he gives an inappropriate response
Verbal Jigsaw	Focus on the use of scientific terminology, keywords and phrases to form integrated propositional statements	For topics with several technical terms; for students weak in language skills
• Association of key words and phrases	Guide students to form a series of propositional statements to form a coherent mental framework	To introduce factual or descriptive information and to reinforce scientific vocabulary
• Verbal cloze	Pause in mid-sentence to allow students to verbally "fill-in-the-blanks" to complete the sentence	To elicit or emphasise keywords and phrases, for students who are not articulate or verbally expressive

Questioning-based Approach and Strategies Used	Features	When Used
Semantic Tapestry	Help students weave disparate ideas together into a conceptual framework like constructing a tapestry of ideas	To focus on ideas and abstract concepts; for topics not associated with an abundance of technical terms
• Multi-pronged questioning	Pose questions from different angles that address multiple aspects of a problem	To help students view a problem from different angles and perspectives
• Stimulating multimodal thinking	Pose questions that involve the use of a range of thinking (e.g. verbal, visual, symbolic, logical-mathematical) using talk, diagrams, visual images, symbols, formulas and calculations	To encourage students to think in a variety of modes and understand the concept from multiple perspectives
• Focusing and zooming	Guide students to think at both the visible, macro level and at the micro or molecular level; or use questions that zoom "in and out", alternating between a big, broad question and more specifically focused, subordinate questions	To help students understand a concept at both the macro, overarching level and the mico, in-depth level
Framing	Use questions to frame a problem, issue, or topic and to structure the discussion that ensues	To help students see the relationship between a question and the information that it addresses
• Question-based prelude	Use question-answer propositions; questions act as an advance organizer and lead-in to information presented subsequently	For expository talk to preface declarative statements and to focus student thinking
• Question-based outline	Present a big, broad question and subordinate or related questions visually (e.g. on slides)	To visually focus students' thinking and help students see the links between the big

Questioning-based Approach and Strategies Used	Features	When Used
		question and subordinate questions
• Question-based summary	Give an overall summary in a question-and-answer format to consolidate the key points	At end of lesson to recapitulate key concepts succintly

An overview plan of workshop

Leading areas for individual journaling and leading questions for group discussions during workshop

Workshop on Questioning	Individual Journal	Group Discussion
Day one, part one Objective: Engage teachers' knowledge and belief on questioning *(30 min)* Workshop Experience: • Reflect and share on teacher questioning individually and with other teachers	At the start of the workshop, get each teacher to reflect on teacher questioning. Leading areas for self reflection: • What I know, what I want to know and what I learn • My observations and beliefs on "inquiry", "learning and thinking" and "questioning" based on a common science video lesson • The roles of teacher questioning in an inquiry science class are … • Some examples of types of questions include… • These types of questions are used (when and how) … .	After individual reflection, get both Primary Four and Primary Five teachers to discuss teacher questioning. Leading questions for group discussion: • What do you know and want to know? • What are your observations and beliefs on "inquiry", "learning and thinking" and "questioning" based on the common science video lesson? • What are the roles of teacher questioning in an inquiry science class? • What are examples of types of questions? • When and how are these types of questions used?

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Workshop on Questioning	Individual Journal	Group Discussion
Day one, part two	After the screening of the four video clips, get each teacher to identify questions and analyse purposes of the questions in the context of the video lessons.	After individual reflection, get both Primary Four and Primary Five teachers to discuss types of questions and their purposes in the context of the video lessons.
Objective:		
Observe and analyse question use in four authentic lessons 1-4*, based on teachers' own knowledge and experience on questioning		
(45 min)		
Workshop Experience:	Leading areas for self reflection:	Leading questions for group discussion:
• View videos of science lessons • Identify questions used and reflect on/discuss the purpose of the questions	• Types of questions observed in each lesson clips include … • The purposes of the questions are to …	• What are the types of questions observed in the lesson? • What are the purposes of these questions?
*These lessons feature the four questioning approaches.		
Lesson 1 - Socratic questioning		
Lesson 2 - Verbal jigsaw		
Lesson 3 - Semantic tapestry		
Lesson 4 – Framing		

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Workshop on Questioning	Individual Journal	Group Discussion
Day one, part three	Get each pair of teachers to read and discuss one questioning approach. Then, have each teacher reflect on the questioning approach (that they focused on) in relation to their own practice and how they can apply.	Get Primary Four and Primary Five teachers to discuss key features for the four questioning approaches; share examples of how the questioning approaches have been used and explore how the questioning approaches can be applied in other topics/contexts.
Objective:		
Gain knowledge and understanding on Chin's questioning approaches (Socratic questioning, verbal jigsaw, semantic tapestry, framing) through learning with other teachers; relate to existing practices; and explore possibilities in other topics/contexts		
(1h 30 min)		
	Leading areas for self reflection:	Leading questions for group discussion:
Workshop Experience:	• Socratic questioning / verbal jigsaw, semantic tapestry / framing is …	• What are the key features of Socratic questioning / verbal jigsaw, semantic tapestry / framing?
• Read and discuss article "Teacher questioning in science classrooms – what approaches stimulate productive thinking" (Chin, 2007) in relation to current practice and possibilities in science teaching and learning	• Socratic questioning / verbal jigsaw, semantic tapestry / framing is featured in lessons 1/2/3/4 …	• Which questioning approaches (Socratic questioning, verbal jigsaw, semantic tapestry, framing) are featured in lessons 1/2/3/4?
	• I have used Socratic questioning / verbal jigsaw, semantic tapestry / framing in my current lessons…	• How have the questioning approaches (Socratic questioning, verbal jigsaw, semantic tapestry, framing) been used in your current science lessons?
	• I can use Socratic questioning / verbal jigsaw, semantic tapestry / framing in other topics/contexts…	• How can the questioning approaches (Socratic questioning, verbal jigsaw, semantic tapestry, framing) be used in other topics/contexts?

Workshop on Questioning	Individual Journal	Group Discussion
Day two Objective: Plan questioning as part of lesson design - Primary Four Topic 1 (two lessons) - Primary Five Topic 1 (two lessons) *(1h 15 min for each lesson)* Workshop Experience: ● Identify learning outcomes and skills ● Determine phases of lesson ● Plan one to two key inquiry questions ● Select one to two questioning approaches and pedagogies	Get each teacher to reflect on how they plan to customise the group lessons plans. Leading areas for self reflection: ● I plan to customise the group lesson plans as follows....	Get teachers to plan questioning as part of lesson design: - Primary Four teachers plan two lessons for a topic to be taught in Semester two. - Primary Five teachers plan two lessons for a topic to be taught in Semester two. Leading questions for group discussion: ● Which learning outcomes are you focusing on? ● What are the phases of the lesson development? ● What are the key inquiry questions? ● Which questioning approaches and pedagogies are you using?

Workshop on Questioning	Individual Journal	Group Discussion
Day three Objective: Reflect and share on learning journey Plan questioning as part of lesson design - Primary Four Topic 2 (two lessons) - Primary Five Topic 2 (two lessons) (1h 15 min for each lesson) Workshop Experience: • reflect on their own learning journey on questioning and share questioning approaches that they have learned, applied and impacted student learning • Identify learning outcomes and skills • Determine phases of lesson • Plan one to two key inquiry questions • Select one to two questioning approaches and pedagogies	Get each teacher to reflect on their learning journey so far before planning to customise the group lessons plans. Leading areas for self reflection: • My learning journey is like this postcard ... • The questioning approach is ... The level of student thinking is ... • I observed / learned the following while customising the two group lesson plans for the last topic ... • I plan to customise the group lesson plans for this topic as follows ...	Get teachers to share their reflections on the learning journey so far before planning questioning as part of lesson design: - Primary Four teachers plan another two lessons for another topic to be taught in Semester two. - Primary Five teachers plan another two lessons for another topic to be taught in Semester two. Leading questions for group discussion: • What questioning approach is used and what is the level of student thinking? • What have you observed / learned while planning the two lessons for the last topic? • Which learning outcomes are you focusing on? • What are the phases of the lesson development? • What are the key inquiry questions? • Which questioning approaches and pedagogies are you using?

Samples of workshop materials
Sample of template for video case analysis at day one workshop

Video clip	First analysis		Second analysis[1]	
	Types of questions observed in each lesson clips include …	The purposes of the questions are to …	Types of questions observed in each lesson clips include …	The purposes of the questions are to …
1				

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[1] After learning about Chin's (2007) questioning approaches, revisit the four video cases to identify the questioning approaches used in each video case.

Sample of template for learning and discussing Chin's (2007) questioning framework

Question-based approach/strategies Used	Features	How I have used in current lessons	How I can use in other lessons
Socratic questioning • Pumping • Reflective toss • Constructive challenge			
Verbal jigsaw • Association of key words and phrases • Verbal cloze			
Semantic tapestry • Multi-pronged questioning • Stimulating multimodal thinking • Focusing and zooming			

Question-based approach/strategies Used	Features	How I have used in current lessons	How I can use in other lessons
Framing • Question - based prelude • Question - based outline • Question - based summary			

Sample of template for lesson planning at day two workshop

Curriculum Outcomes:

Phases of Lesson Development and Pedagogies:

Pedagogies:

Questioning Approaches / Strategies:

Key Inquiry Questions:

Samples of discussion cases at day three workshop

Discussion case 1

Level: Primary Four
Topic: Heat Conduction
Lesson: Students had hands-on investigation to find out which material
              (metal, ceramics and styrofoam) is a better conductor of heat. They
              used datalogger to measure the temperature of water over 15
              minutes.

Learning Experiences:

Whole Class Discussion Relate the current investigation to a previous investigation *(See Discussion Case 1a)*	**Whole Class Discussion** Discuss the investigation before conducting the hands-on investigation *(See Discussion Case 1b)*
Group Investigation Measure temperature of water in three cups made of different materials, using dataloggers *(See Discussion Case 1c)*	**Group Investigation** **Whole Class Discussion** Discuss data collected, whether it was the temperature of hot water or surroundings? *(See Discussion Case 1d)*
Whole Class Discussion Apply concepts in everyday life – how mummy is able to cook food fast and not get burned by cooking pot *(See Discussion Case 1e)*	**Whole Class Discussion** Apply concepts in everyday life – keeping drinks cold while attending national day parade *(See Discussion Case 1f)*

Discussion Case 1a

Level: Primary Four
Topic: Heat conduction
Lesson: Students had hands-on investigation to find out which material
                     (metal, ceramics and styrofoam) is a better conductor of heat. They
                     used datalogger to measure the temperature of water over 15
                     minutes.
Context of Discourse: Teacher provided opportunity for students to relate the current
                     investigation to a previous investigation

T	Do you remember the experiment we do regarding the thumbtacks and the wax?
S	(Students responded in chorus) Yes.
T	What did we use?
S	Metal rod.
T	We used the metal rod, right?
S	Bunsen burner.
T	Yes...the Bunsen burner. And then, can you remember what happened to the thumbtacks? J?
S	The thumbtack closest to the flame will drop first.
T	The thumbtack closed to the source of the heat dropped first. Followed by the next one that was nearer, followed by the last one. Now, do you think heat had flowed in the experiment in the rod?
S	(Students responded in chorus) Yes.
T	But, we did not see heat flow, right? Heat flow cannot be seen. How did we know that heat flow had actually happened? How do we know? Because, the rod did not change colour. Did not change to red, right? Red hot...So, it is not visible to our eyes. How do we know that heat flow has occurred? K?
S	The wax melted.
T	Because the wax melted. So, what made the wax melt?
S	The heat in the rod.
T	Where did the heat in the rod come from?
S	Candle.
T	From the candle. From the source of heat. So, therefore, even though we cannot see heat flow, we know that heat flow has occurred because the wax melted. The wax gained heat and melted. Very good. Suppose, instead of the iron rod...the metal rod, I use a ceramic rod. Do you think the wax will melt and the thumbtacks will drop?
S	(Students responded in chorus) No.
T	Who say no?
S	(Some students raised their hands)
T	Quite a number. Who say yes?

S	(Some students raised their hands)
T	These two say yes. Let's hear from them first. Who wants to offer answers? N, would you like to try? N, you said yes, right? Why? You said yes. It will still happen, correct? Why?
S	Ceramic rod works the same as metal rod.
T	Ceramic rod works the same as metal rod. (Teacher drew rod with thumbtacks on the board) P, you said yes. Can you tell me why you say yes? The thumbtacks will drop. Yes, why?
S	Ceramic is also a conductor of heat.
T	P says that ceramic is also a conductor of heat. So, you are suggesting that ceramic also allows the heat to flow?
S	Yes.
T	How about those who said don't have? Who would like to offer an answer? Those who said don't know just now. Who are those of say it will not work? Put up your hand. The hands "disappeared". Did you change your mind?
S	Teacher, I change.
T	Some change your mind. C says no – thumbtacks will not drop if I do the same experiment. Here (the rod), instead of metal, it is ceramic.
S	Ceramic is a poor conductor of heat.
T	Ceramic is a poor conductor of heat. What do you mean by poor conductor of heat? She says no because she says ceramic is a poor conductor of heat. So, are you suggesting that …there is heat flow or not? Yes or no?
S	It will still flow.
T	She is saying that it will still flow.
S	Slowly.
T	Oh…flow slowly. So, the heat flow is slow.
S	Not so easy to flow.
T	Not so easy to flow, is it? Very good. She has the correct idea. That heat flow is very very slow.

Discussion Case 1b

Level: Primary Four
Topic: Heat conduction
Lesson: Students had hands-on investigation to find out which material
                (metal, ceramics and styrofoam) is a better conductor of heat.
                They used datalogger to measure the temperature of water over 15
                minutes.
Context of Discourse:
Teacher provided opportunity for students to discuss the investigation before
conducting the hands-on investigation.

T	What is the aim of the experiment?
S	To find out which material is a better conductor of heat.
T	What are the variables we have to keep constant? Remember we spoke about variables in one of our lessons? What are the variables we have to keep constant so that we can measure which materials are good or poor conductors?
S	Heat travel from hotter objects to colder objects.
T	That is a concept. I am asking you… What are the variables you must keep constant? Yes, H?
S	Temperature of hot water.
T	Temperature of the hot water. Very good. Yes?
S	Volume of water.
T	Volume of water. Amount of water. Anyone else?
S	The beaker.
T	The beaker. What do you mean by the beaker? The type or the glass or the amount?
S	The type.
T	The type of beaker must be constant. Here we are measuring whether different materials conduct heat fast or slow. If we use same type of beaker or material, are we doing the experiment correctly?
S	Yes…No.
T	Do we change the type of beaker?
S	Yes.
T	Anyone else? Any other things else that you have to keep constant? You said the amount of water. You said size of the beaker. The experiment here, we are going to do is to find out which material of the beaker conducts more heat and which conducts less heat. Which material beaker? Can you use the same type of beaker?
S	No.
T	The variable is constant or different?
S	Different.
T	Very good. Let's look at what are the materials and apparatus you need. Iq, name me one material that you need.
S	Beaker.

T	Beaker. Alright. Other materials, HA?
S	Plastic cup.
T	Plastic cup. Class, I need to explain this to you. The beaker is the beaker that you are pouring water has to be the same. But, the cup that we are using are?
S	Different.
T	Different cups. The beaker that we are pouring hot water. We are not using that beaker to measure temperature. The material you are using is the cup. You are right. The beaker must be constant. But, what must be different?
S	The material.
T	Material of the?
S	Cup.
T	OK. What cups are we using? WL?
S	Plastic.
T	Some more?
S	Metal.
T	One more material? What are we using?
S	Foam cup.
T	Foam...Styrofoam cup. What other apparatus are we using?
S	Datalogger.
T	Datalogger.
S	And heat sensors.

Materials used in "heat flow" lesson

Aim:
To find out how heat flows

Materials needed:
Bunsen burner
Metal rod
Retort stand
Candle
Match
Thumbtacks

Procedure:
1. Attach three thumbtacks, A, B and C onto the metal rod using candle wax.
2. Predict which thumbtack will drop off first.
3. Turn on the Bunsen burner and heat up the rod at one end.
4. Observe and record which thumbtack will drop off first.

Iron rod

A   B   C

— Bunsen burner
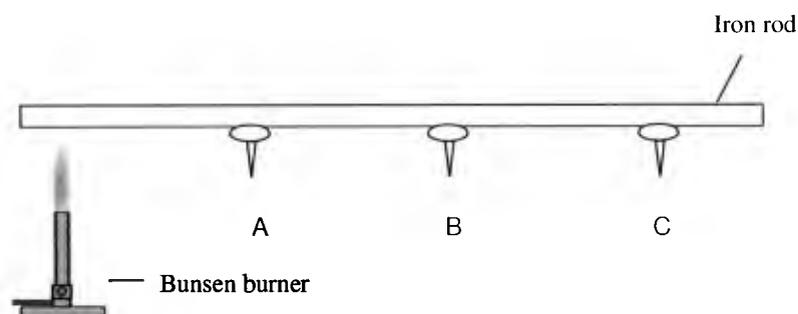
Results:
1.   Thumbtack _____ drops off first, followed by thumbtack
             _____ and thumbtack _____.

2.   Draw an arrow in the diagram to show the direction of heat.

Conclusion:
Heat flows from a _____ place to a _____
place until both reach the same _____.

Examples of cases for students' application of concept of heat flow:

- A candle is now placed in the middle of the rod.
- Recall: How does heat flow?
- Which direction do you think heat will flow in this case?
- Discuss with your partner and see if he/she agrees with you.

Which coin did he pick?

Teacher will have a few similar coins, for example, five one-dollar coins and place them on a bench in any order.

While teacher is not looking, a student will pick any coin and hold it tightly in his hand for 15 seconds then place the coin back on the bench. (Another student will be the timer and another will make sure teacher does not peek).

Question: Will the teacher know which coin the student picks?

(Remember teacher is not looking when the student picks the coin and places it back)

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What we have learned:

1.   Heat is the amount of _____ that makes things hot.

2.   Temperature is how _____ or cold an object is.

3.   Heat flows from a _____ place to a _____
        place until both reaches the _____ temperature.

4.   When an object gains heat, its temperature _____.

5.   When an object loses heat, its temperature _____.

6.   Write down 'gains heat' or 'loses heat' in the space below:

a.   Yong Yee says, "My ice cream is melting!" The ice cream
        _____ from the surroundings. Heat flows from
        _____ to _____.

b.   Mdm Yeo says, "Oh dear, my tea has turned cold". The tea
        _____ to the surroundings. Heat flows from
        _____ to the _____.

Materials used in "heat conduct" lesson

Aim:

To find out which material is a better conductor of heat

Materials needed:

Beaker
Hot water
Metal cup
Ceramic cup
Foam cup
Data loggers and heat sensors

Procedure:

1. Pour hot water into three cups made of different materials.
2. Turn on the data logger and put the heat sensor into the water and keep it there.
3. Observe the temperature change of the water.
4. At the end of the experiment, record the temperature readings in the results table.

Results:

Type of Cup	Temperature (°C)					Which cup is the slowest to lose heat? Tick ✓
	Start Time	5 minutes	10 minutes	15 minutes	20 minutes	
Metal						
Ceramic						
Foam						

Explanation and Conclusion:

4. The water in the _____ cup loses heat the slowest
because

☐ heat is able to flow through it easily.
☐ heat is <u>not</u> able to flow through it easily.

5. The water in the _____ cup loses heat the fastest because

☐ heat is able to flow through it easily.
☐ heat is <u>not</u> able to flow through it easily.

Hint: Do you want heat to flow easily?

*6. If I want my hot drink to cool down faster, I will pour my drink into a

☐ metal cup
☐ foam cup

*7. If I want my hot drink to remain hot for a longer time, I will pour my
drink into a

☐ metal cup
☐ foam cup

Materials used in "light (transparency)" lesson

Aim:

To find out whether different materials allow light to pass through

Materials needed:

Torchlight, clear plastic sheet, tracing paper, cardboard, data logger

Procedure:

1.   Switch on the torch and shine the torch at each object.
2.   Observe and complete the table below:

Observation and Results:

Objects	Amount of light that passed through
No Object	
Clear Plastic/Transparency	
Tracing Paper	
Cardboard	

Conclusion:

a) Clear plastic _____

    It is _____.

b) Tracing paper _____

    It is _____.

c) Cardboard _____

    It is _____.

Conclusion:

What can you conclude from the experiment?

Extension:

Examples of transparent materials	Objects that can be made
Examples of translucent materials	Objects that can be made
Examples of opaque materials	Objects that can be made

Materials used in "light (shadow)" lesson

Aim: To find out how shadows are formed

Materials needed: Torchlight, Plastic Cup, Screen

Procedure:

1.   Switch off all the lights in the room.
2.   Switch on the torch.
3.   Shine the torch at the cup at different angles – Positions 1, 2 and 3.
4.   Observe and complete the table below:

Position 1:

Draw the shadow here.

Position 2:
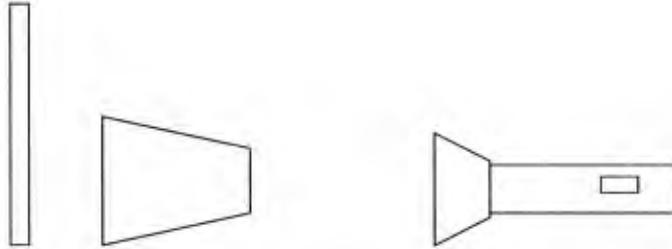
Draw the shadow here.

Position 3:
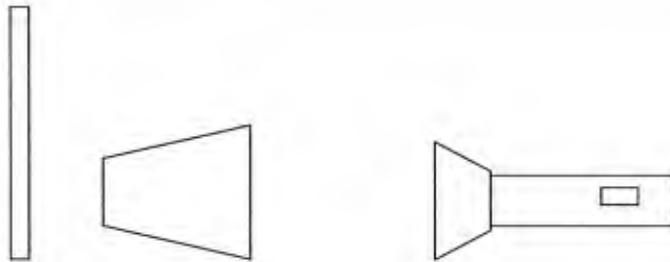
Draw the shadow here.
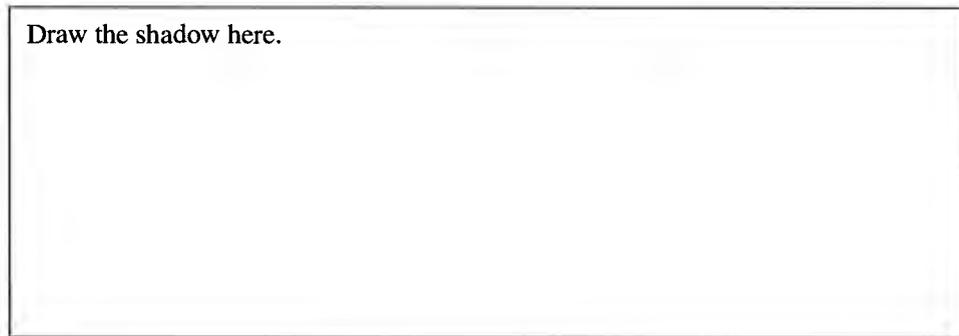
What can you observe about the shapes and sizes of the shadows in positions 2 and 3?

Position 4:

Draw shadow 4 here.
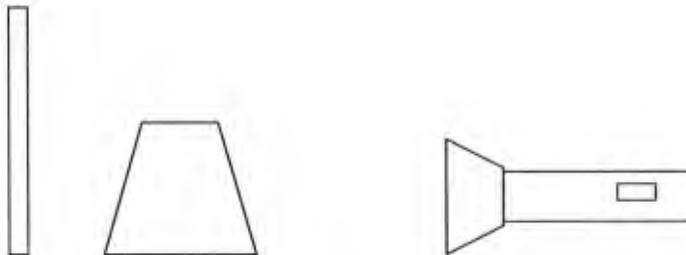
Conclusion:

1)   When light is completely or partially _____, a shadow is formed.

2)   The shape of the shadow may c_____ when the object is put in different positions.

Aim: To find out how a shadow changes when the distance between the light source and the object changes.

Materials needed: Torchlight, Plastic Cup, Screen

Procedure:

1.   Set up the materials as shown in the diagram below.
2.   Position the torch at the first position.
3.   Observe the height of the shadow and complete the table to record your observation.

15 cm

First Position

10 cm

Second Position

5 cm

Third Position
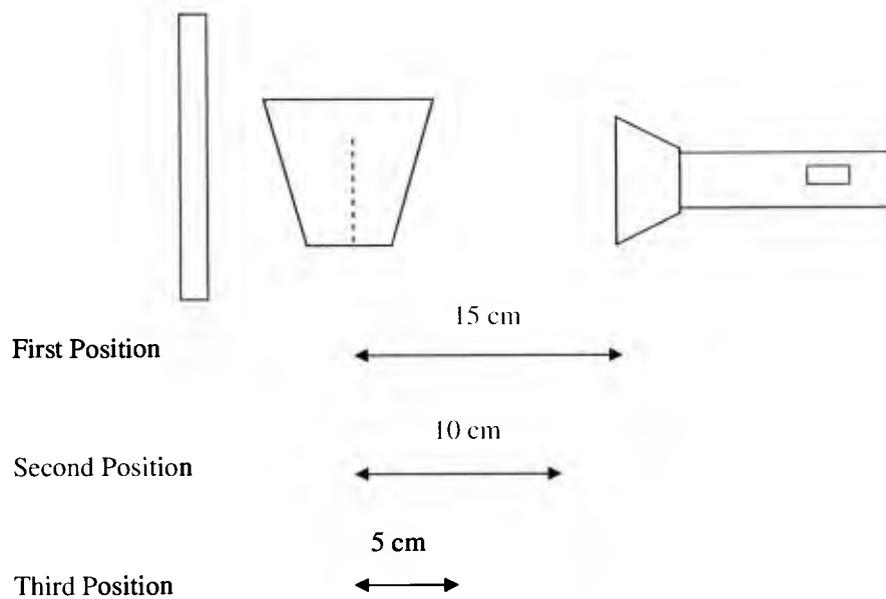
Results:

Distance between cup and torch	Height of the shadow	Width of the shadow
15 cm		
10 cm		
5 cm		

4. What did you notice about the distance between the cup and the torch and the height of the shadow?

When the distance between the cup and torch decreases, the size of the shadow _____.

When the distance between the cup and the torch increases, the size of the shadow _____.

Conclusion:

1)   The greater the distance between the object and the light source, the _____ is the shadow.

2)   The shorter the distance between the object and the light source, the _____ the shadow.

Extension:

Peter uses his hands to form the shadow of a bird. If he wants the shadow to be bigger, what must he do?

Materials used in "plant reproduction" lesson

Instructions for Role Play:

You will work as a group to role play the process assigned to you.
Read the handout given to you.
Discuss with each other what you understand about the process after your reading.
Try to explain how the process occurs by using props to demonstrate it.
You may use labels (eg. stigma) to identify the roles played.

Pollination

The flower below contains both the male and female parts. The male parts are the anther, filament and pollen grains. The female parts consist of the stigma, style, ovary and ovules.
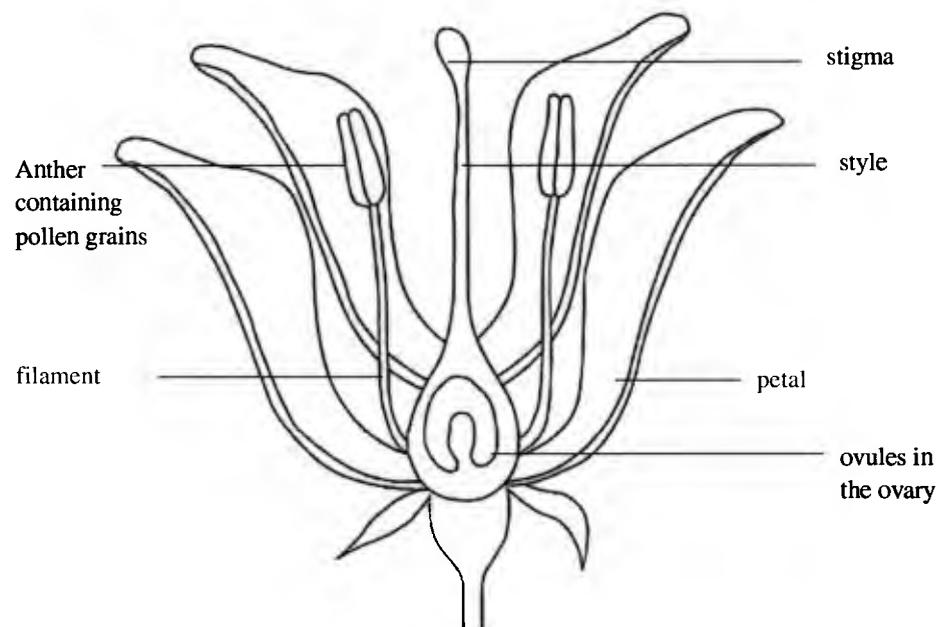
When the pollen grains are released, wind or animals are necessary for their transfer to the stigma of the flower. This process is called pollination.

Fertilisation

The flower below contains both the male and female parts. The male parts are the anther, filament and pollen grains. The female parts consist of the stigma, style, ovary and ovules.

Anther containing pollen grains

filament

stigma

style

petal

ovules in the ovary
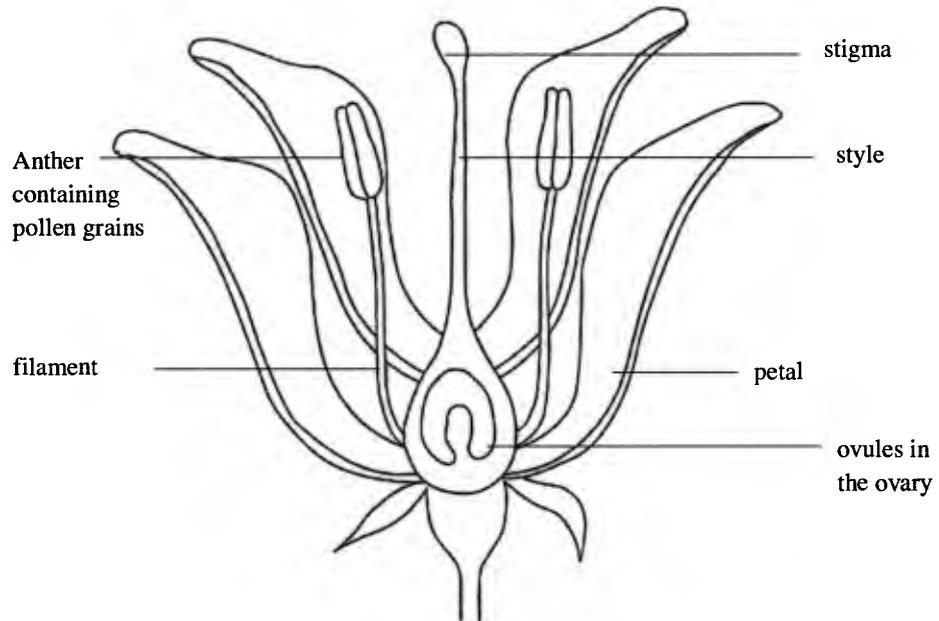
When the pollen grains are released, wind or animals are necessary for their transfer to the stigma of the flower. This process is called pollination.

When the pollen grain lands on the stigma, it grows a tube into the stigma and down the style, towards the ovules. Once it enters the ovule, the male cell fuses with the egg cell. This process is called fertilisation. After fertilisation occurs, the ovary becomes the fruit and the ovule becomes the seed.

Seed Dispersal

The first stage in the life cycle of a flowering plant is the seed. In order for seeds to grow into new plants, they need to be carried away from the parent plant. This can be achieved in the following ways:

By Wind

Seeds that are dispersed by wind are usually small, light and may have special structures resembling parachutes or wings e.g. Angsana, Shorea. These structures enable them to be dispersed away from their parent plants.

By Animals

Seeds that are scattered by animals usually have fleshy and juicy fruits. Animals eat the fleshy parts and disperse the inedible seeds e.g. Mango. Sometimes, the seeds are so small that they are eaten together with the fleshy part and passed out in the droppings of the animals.

Some fruits and seeds scattered by animals are dry and have hook-like structures to attach to the bodies of animals e.g. Love Grass.

By Water

Seeds dispersed by water usually grow near the edge of water. They have structures such as fibrous husks which trap air to enable them to float on water e.g. Coconut.

By Splitting of the Fruit

Some plants have fruits that are dry and split open when ripe e.g. Flame of the Forest. This action releases the seeds far away from the parent plant.

Germination

The baby plant is protected inside the seed. Seeds require warm and moist conditions in order to germinate. The baby plant uses the stored food to grow.

When the seed starts to germinate, the first thing that appears is the root. The tiny shoot grows next. This is the beginning of a young plant. The root grows downwards while the shoot grows upwards.

Materials used in "plant dispersal" lesson

In the boxes, tick the characteristic(s) which your fruit has.

Characteristics	Tick here
Soft to touch	
Brown in colour when ripe	
Juicy flesh	
Dry and hard or papery when ripe	
Has wing-like structures	
Has fibrous husks	
Has waterproof covering	
Has hooks	
Has parachutes of hair	
Small seeds, less than 1cm long or wide	
Able to float in water	

Draw your fruit / seed in this box
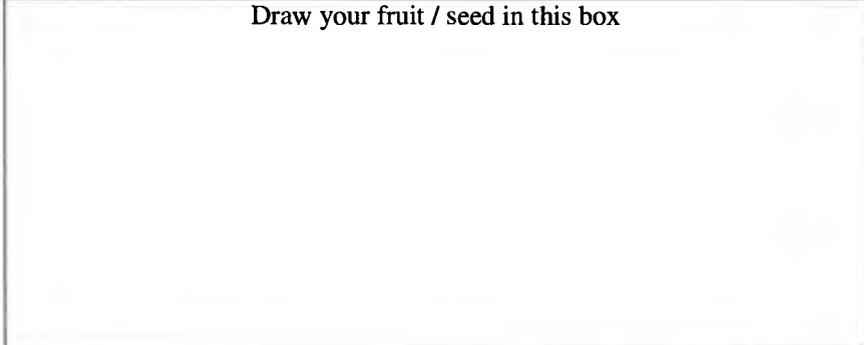
How do you think the seeds of your fruit are being dispersed?

Justify your answer.

Table J-1

An overview plan of lesson on heat transfer

Curriculum outcomes:
Show an understanding that heat flows from a hotter to a colder object until both reach the same temperature

Phases of lesson development:

(1) Experiment phase (Teachers conducted a demonstration to show heat transfer in a metal rod with several thumb tacks attached)

(2) Real life situation phase (Teachers facilitated whole class discussion on heat transfer in everyday examples such as a cup of coffee and a bowl of hot soup noodles; coin experiment)

Key inquiry questions:	*Questioning approach:* Framing
(1) Experiment phase	*Sub-questions:*
How do things become hot or cold?	What is step 1?
	What is step 2?
	What will happen?
	Which thumb tack will drop first? Why?
	Which thumb tack will drop next? Why?
	What is the direction of heat flow?
(2) Real life situation phase	*Sub-questions:*
How does heat gain or loss affect temperature?	How does the mug feel to his touch?
	Is it still cold? Why?
	What is the direction of heat flow?
	What will the temperature of the soup noodle be?
	Will it be still hot? Why?
	What is the direction of heat flow?

Table J-2

An overview plan of lesson on plant reproduction

Key ideas:

- Parts and functions of the flower e.g. petal, stigma, anther, style, ovary, ovules.
- Processes of pollination, fertilisation, seed dispersal and germination.

Key questioning approach: Socratic questioning

Key questions:

- What are the different parts and functions of a flower?
- What are pollination, fertilisation, seed dispersal and germination?
- How do you use suitable things to role play the processes of pollination, fertilisation, seed dispersal and germination?

Skills and processes:

- Observation, inference, questioning

Ethics and attitudes:

- Value individual effort and teamwork

Suggested pedagogies / strategies

- Group work / discussion

Table J-3

An overview plan of lesson on heat conduction

Curriculum outcomes:
Show an understanding that heat flows at different rates through different materials

Phases of lesson development:
(1) Experiment phase (Students, in groups of six, measured temperature of hot water over time in three cups – ceramic cup, metal cup, styrofoam cup) (2) Real life situation phase (Teacher facilitated whole class discussion on use of different materials in making everyday objects such as different parts of frying pans)

Key inquiry questions:	*Questioning approach:* Framing
Does heat flow easily in all materials? How does heat gain or loss affect temperature?	*Advance organiser to frame thinking* • Who can recall how heat flows? • Do you remember the experiment on the thumbtacks and wax? What kind of rod did we use? How did we know that heat flow occurred in that experiment? • If we conduct a similar experiment using a ceramic rod, will the thumbtacks drop off faster? What if we use a plastic rod? (Misconception – heat will not flow through plastic) • If I place the flame near a hard plastic rod (the kind of plastic we use for our water bottle) and not let the flame touch the plastic rod, what will happen to the area that is nearest to the flame?
	Experiment • What is the first step we need to do? What is the second step we need to do? • What can the datalogger measure? Based on your results, what can you say about the different materials in terms of heat loss?

Table J-4

An overview plan of lesson on plant dispersal

Key ideas:

Seeds and fruits are dispersed so as to prevent overcrowding and dispersal can be through water, wind, animals, and explosive action.

Key questioning approach: Socratic questioning

Key questions:

- What is seed dispersal?
- Why is there a need for seed dispersal?
- How are seeds dispersed?

Other questions:

- What do you know about seeds?
- Why do plants have seeds?
- Where can you find seeds? Which part of the plant can you find them?
- How might we describe some fruits? (List these on the board: round, light, heavy, sticky, winged, feathery as possible answers)
- Why do you think seeds are found in fruits?
- What function do you think fruits serve?
- Why do you think dispersal is important for the plant?
- How do you think the different characteristics are related to the functions of fruit?
- Which of the three seeds would most likely be dispersed by an animal? Why?

Skills and processes:

- Observation, inference, questioning

Ethics and attitudes:

- Value individual effort and teamwork

Suggested pedagogies / strategies

- Group work / discussion

Table J-5
An overview plan of lesson on light and transparency

Curriculum outcomes:

Investigate the transparency of materials to light and communicate findings

Generate ideas on the types of materials that are suitable to make objects to apply learning

Phases of lesson development:

(1) Tuning in phase (Teacher facilitated whole class discussion to get students recapitulate concepts of light)

(2) Experiment phase (Teacher facilitated guided experiment to have students investigate the transparency of different materials in groups of six)

(3) Summary (Teacher facilitated whole class discussion to elicit students' learning)

Key inquiry questions: Does light pass through different types of materials?

Questioning approaches: Verbal jigsaw, Socratic questioning, Framing

Tuning in

- What did we learn about light?; Can light pass through objects?

Experiment

- What is your reading?; Do you see a pattern?; Did the material allow light to pass through?

- What is the changed variable for today's experiment?; What are the fixed variables?; If I decide to change the type of torch used for the third material, will this be a fair test? Why?

Worksheet

- What are examples of transparent / translucent /opaque materials?; What objects can be made using transparent / translucent / opaque materials?

Conclusion

- From the experiment that we have done today, and based on the data we have found out, what have we learned?

- If a transparent object allows some light to pass through, what happens to the other part of the light that did not pass through?

Table J-6
An overview plan of lesson on plant transport

Key ideas:

- Parts of the plant transport system are water-carrying tubes and food-carrying tubes.
- Water-carrying tubes carry water from the roots to all other parts of the plant.
- Food-carrying tubes carry food from the leaves to all other parts of the plant.

Key questioning approach: Socratic questioning

Key questions:

- What make up the plant transport system?
- What are their respective functions?

Other questions:

- What do you think happened to make the edges of this flower blue?
- What can we do if we want to create a carnation of blue and red?
- Where did the coloured water start?; How does water reach the different parts?; What parts of the plants are involved?
- Are the coloured stains everywhere or just in specific parts?

Skills and processes:

- Analysing, identifying, observing, comparing, evaluating

Ethics and attitudes:

- Value individual effort and teamwork

Suggested pedagogies / strategies

- Group work / discussion

Table J-7
An overview plan of lesson on light and shadow

Curriculum outcomes:

Investigate how shadows are formed
Know that positions of object and the light source affect the shape and size of a shadow

Phases of lesson development:

(1) Tuning in phase (Teacher facilitated whole class discussion to get students recapitulate concepts of light)

(2) Experiment phase (Teacher facilitated guided experiment to have students investigate how shadows are formed)

(3) Summary (Teacher facilitate whole class discussion to elicit students' learning)

Key inquiry questions: How shadows are formed? ; How does a shadow change when the distance between the light source and the object change?

Questioning approaches: Verbal jigsaw, Socratic questioning, Framing

Tuning in

• What happens when light is blocked by an opaque object?

Experiment

• Was there a shadow?; What material is the cup made of?; Why is there a shadow?

• What is the shape of the shadow at position one/two/three?; What is the difference in the shapes in positions two and three?; Can the shape of the shadow change when the cup is put in different positions?

• What is the height and width of the shadow when the distance between the torch and cup is 15/10/6cm?; Is there a pattern? What is the pattern?; How does a shadow change when the distance between the light and the object is changed?

Conclusion

• From the experiment that we have done today and based on the data we have found out, what have we learned? Does a transparent object produce a shadow?

Table J-8

An overview plan of lesson on plant processes

Key idea:
Plants consist of systems which work together to ensure its survival.
Living things need air, food and water in order to survive.
Systems in a plant make use of these essentials to carry out life processes for the plant's survival.
Key questioning approach: Semantic tapestry
Key questions:
What do living things need in order to survive?
What are the functions of the plant systems in ensuring its survival?
Skills and processes:
Identifying and presenting the links between the processes carried out by plant systems.
Ethics and attitudes:
Value individual effort and teamwork
Suggested pedagogies / strategies
Group work / discussion