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Supporting Teachers to Develop Substantive Discourse in Primary Science Classrooms

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Abstract: Students' thinking and learning in inquiry-based science is contingent on them being able to participate in substantive conversations so they explore their ideas and develop reasons and explanations for the outcomes of their investigations.
While teachers understand the importance of talk for student learning, they are often unaware of the impact of their discourse practice on the quality of classroom talk. To develop substantive classroom discourse, first teachers need to understand what substantive talk looks and sounds like, and then they need to develop their capacity to use questioning and discourse moves to achieve such talk. Science poses additional challenges for teachers in that the form of discourse needs to be matched to the instructional purpose of the phase of inquiry.
This article presents the findings of a study which documented the learning of primary school teachers participating in a professional learning intervention focussed on developing their capacity to manage discourse in science lessons. The article outlines the repertoire of questioning and discourse moves the teachers came to use to develop substantive whole-class discussions.

Introduction

In science education, it is important for students to be able to examine evidence and argue the merits of knowledge claims, which goes to the heart of scientific literacy (Osborne, Erduran & Simon, 2004). As such, students need to be explicitly scaffolded in how to use scientific language as well as how to think about their interpretations of evidence and the arguments they develop about science phenomena (Gee, 2004; Hackling & Sherriff, 2015). Inquiry-based and constructivist approaches to teaching science facilitate such a focus by supporting learners to actively construct knowledge, and to make personal meaning from their shared experiences by drawing on their prior knowledge and by interacting with their environment, teachers and peers (Driver, Asoko, Leach, Mortimer & Scott, 1994; Nystrand, 1997). Chin (2007) argues that in inquiry-based classrooms "the teacher's intent is to elicit what students think (such as their explanations and predictions, especially if these are different from what scientists think), encourage them to elaborate on their previous answers and ideas, and to help students construct conceptual knowledge" (p. 818). Meaning is seen to be developed via substantive discourse and learners come to understand scientific concepts and ideas as they are constructed in conversation (Driver et al., 1994; Mercer, Dawes, Wegerif, & Sams, 2004. Setting up a coherent series of learning opportunities so that the learning is 'stretched-out-in-time' (Scott, Ametller, Dawes, Kleine, & Mercer, 2007) gives teachers the chance to explore students' everyday views and to provide experiences that subsequently allow the students to investigate new concepts and talk through their developing ideas as an investigation proceeds. In this way, students come to understand how the scientific view compares and contrasts with their personal view and how it is used to explain scientific phenomenon (Driver et al., 1994; Traianou, 2007).

Alexander (2006) found talk that fosters students' capacity to reason is often lacking in many British and American primary school classrooms. Australian research has also demonstrated how classroom pedagogy impacts on the development of students' problem solving capacity and understandings, and how teachers need to expand their pedagogic repertoires to facilitate students' development of deeper levels of knowledge and intellectual engagement (Education Queensland, 2001). Freebody and Luke (2003) also maintain that teachers' capacity to use classroom discourse, scaffold the metalanguage of content area discourses and deepen student learning through sustained conversation are crucial to increasing students' intellectual development.

When analysing the ways in which teachers use language to support students' developing understandings in science, Mortimer and Scott (2003) identified four different classes of communicative approach, including: Interactive-Dialogic, where the teacher and students explore different ideas and points of view; Non-interactive-Dialogic, where the teacher considers various ideas and points of view; Interactive-Authoritative, where the teacher leads the students through a sequence of questions so as to reach a specific point of view; and, Non-interactive-Authoritative, where the teacher presents one specific point of view. In the course of orchestrating a sequence of inquiry-based science lessons, the instructional purposes change not only for each lesson but also for each phase of a lesson. Consequently, teachers need to understand how to utilise different communicative approaches to realise a range of instructional purposes and how to move between dialogic and authoritative modes of talk to achieve this (Scott et al., 2007).

The *Primary Connections* program (Australian Academy of Science, 2005) is a well-recognised Australian primary science teaching resource. It is based on a social constructivist teaching and learning model that utilises an inquiry-based approach to teaching where students' ideas and understandings of science are extended via talk and social interaction. The program is based on the 5Es model (Hackling, Peers & Prain, 2007), which incorporates five phases of inquiry (Engage, Explore, Explain, Elaborate and Evaluate). These phases are designed to facilitate conceptual change, with each one having a specific function in guiding students' active construction of scientific understandings.

Hackling, Smith and Murcia (2010; 2011) argue that teachers need to adjust their style of interaction in classroom discourse so that they match their communicative approach to the phase of scientific inquiry. In the Engage and Explore phases, where the instructional purpose is to engage students in dialogue and explore their ideas about a topic, interactive and dialogic approaches are required. However, in the Explain phase, the purpose is to accommodate students' views towards the scientific explanation, and a more authoritative approach is required. Table 1 illustrates how Hackling et al. (2010) link Mortimer and Scott's (2003) communicative approaches, suitable question types, wait time and discourse moves to the Engage and Explore phases and also to the Explain phase of inquiry.

Communicative approach	Question types	Wait time	Discourse moves
Interactive-dialogic (many voices and many ideas) for eliciting and exploring students' ideas in the **Engage** and **Explore** phases of inquiry.	More open questions and fewer closed questions.	Longer wait times.	Less evaluation of student answers. More follow-up questions seeking clarification of ideas and seeking other ideas.
Interactive-authoritative (many voices and one idea) for developing science explanations in the **Explain** phase.	More focussed and closed questions.	Shorter wait times.	More evaluation of student answers. More follow-up questions seeking further explanation and justification.

Table 1: Question types, wait times and discourse moves required to implement communicative approaches (based on Hackling et al., 2010).

In order to achieve sustainable improvements in students' learning in science there is a need to improve primary teachers' pedagogical content knowledge for managing classroom discourse. Given that sustaining classroom conversation of high intellectual quality has been recognised as an essential pedagogy (Freebody & Luke, 2003), it is important to investigate how teachers can be supported to manage classroom discourse so that: their communicative approach matches the phase of inquiry; substantive discourse of high intellectual quality is developed; and, student engagement is sustained. However, it should be noted that previous research indicates that orchestrating productive classroom talk is not easy for many teachers (Harris, Phillips & Penuel, 2012; Pimental & McNeill, 2013).

Purpose

The purpose of this study was to investigate the impact of an action-research professional learning program on primary teachers' management of substantive classroom discourse in science lessons so that discourse is shaped to match the instructional purpose of the phase of inquiry. More particularly, the study explored the repertoire of questioning and discourse moves the teachers used as they learned to adjust their communicative approach during substantive whole-class discussions.

Review of Literature

Understanding how to examine the coherence of evidence and to argue over the merits of knowledge claims is particularly important in science education. Alexander (2006) argues that talk is the foundation of all learning and that the quality of student learning is closely linked to the quality of classroom talk. He states that both student engagement and teacher intervention is required to support the development of an individual's capacity to think and to acquire knowledge. This section considers how more and less productive aspects of classroom talk impact on the development of thinking and reasoning.

Less Productive Classroom Talk

Less productive, but very common, aspects of classroom talk revealed by studies of British classrooms and reported by Alexander (2006) included a scarcity of interaction that challenged students to think for themselves. Teachers' questioning, characterised by closed questions, seemed to present low levels of cognitive challenge. Teachers also seemed to give 'bland', all-purpose praise rather than targeted feedback that diagnosed or informed students.

Similar research into American classrooms (Nystrand, Gamoran, Kachy, & Prendergast, 1997) found a prevailing use of the question-answer ‘recitation script’ that resulted in monologic classroom discourse. In addition, teachers generated all the questions, few of which were authentic, and they rarely followed-up students’ responses.

Linguistic research into classroom discourse confirms these findings and highlights similar kinds of interactive patterns, some of which are ingrained in teachers’ practice. The question-answer ‘recitation script’ (Nystrand et al., 1997) is associated with teachers controlling the discourse. Lemke (1990) maintains its use ensures teachers control not only the topic of discussion, but also which students answer their questions and which answers are deemed correct. In this scenario, teachers follow a tightly scripted lesson to ensure topics are ‘covered’ and they use questioning to check on students’ knowledge. This form of interaction follows an I-R-E pattern (Mehan, 1979) where the teacher asks questions (Initiation), listens to students’ answers (Response), and assesses the correctness of these responses (Evaluation). This three-turn structure, also referred to as I-R-F (Initiation-Response-Feedback) (Sinclair & Coulthard, 1975) or triadic dialogue (Lemke, 1990), is used in all classrooms (Mortimer & Scott, 2003). When the I-R-E (I-R-F) pattern of interaction dominates classroom discourse, the possibility of sustained conversation is shut down, the opportunity for students to talk through their ideas is lost, and teachers are unable to gauge students’ understandings or misunderstandings because they cannot hear how students talk about a topic (Lemke, 1990).

The main purpose of questioning in teaching is to promote students’ learning. Furthermore, a positive classroom climate and the type of questioning generated by teachers and students establishes the culture for discourse and dictates the quality of the learning in a classroom (Morgan & Saxton, 1991). When the instructional objectives are focused on knowledge reproduction, as described above, teachers tend to focus on transmitting knowledge by using closed-ended questions. This ensures that only pre-specified responses will be received (Koufetta-Menicou & Scaife, 2000) and that students ‘get the content’ (Erodgan & Campbell, 2008). Pimental and McNeill (2013) noted that due to time constraints, secondary science teachers often focus on content coverage at the expense of developing and extending students’ understandings. However, questioning that is employed more productively can be used as a tool for teachers to facilitate students’ engagement and challenge them to think and reason for themselves.

More Productive Classroom Talk

Alexander (2006) also reviewed studies of European classrooms that revealed a different picture of interaction and uses of talk. Some of the features of more productive interaction included a cognitive purpose for talk that focused on building students’ capacity to think and reason, and sustained interactions between teachers and students over a sequence of several question-answer exchanges. Teachers asked questions that promoted reasoning as opposed to right answers, and they used wait time (Rowe, 1972; Tobin, 1987) to encourage students to think things out and to think aloud. Students’ ‘wrong’ answers were treated as a way into understanding, and teachers provided honest feedback and diagnosis on which students could build. Tytler and Aranda’s (2015) analysis of expert teachers classroom discourse revealed that their discourse moves served three broad purposes: “to elicit and acknowledge student responses, to clarify and to extend student ideas” (p. 425).

When the instructional emphasis is on knowledge construction, as is evident in the scenario above, teachers facilitate students’ active inquiry by asking a significantly greater number of open-ended questions that stimulate productive activity in the inquiry process (Koufetta-Menicou & Scaife, 2000). Smart and Marshall (2013) note that where higher order questions were used, students "engaged at deeper levels with science concepts, formulating hypotheses and using evidence to draw conclusions about phenomenon" (p. 265). In this context, teachers use guided discussion to develop students' conceptual understandings by building on their previous experiences, and diagnosing and refining their ideas (Erodgan & Campbell, 2008). A range of students' ideas are received, and teachers use questioning to prompt and challenge thinking and reasoning (Erodgan & Campbell, 2008; Koufetta-Menicou & Scaife, 2000). Teachers also scaffold students' interactions by asking them for clarification or elaboration, and by using wait time or 'practicing quietness' to give them the chance to make sense of their own ideas (van Zee, Iwasyk, Kurose, Simpson & Wild, 2001).

Koufetta-Menicou and Scaife (2000) found there is a strong correlation between teachers' use of open-ended and higher-order questions and students' metacognitive awareness. They argue that teachers are more effective in developing higher-level thinking when they ask higher-order questions that call for students to: make and justify judgements, arguments or explanations; develop hypotheses; or, make predictions and draw conclusions. Additionally, Erdogan and Campbell (2008) observed that the use of closed-ended questions tends to focus the interaction on subject-matter, which leads to pre-specified responses or 'right answers'. While open-ended questions open up the interaction, eliciting students' thinking and allowing for the exploration of various lines of reasoning (Erodgan & Campbell, 2008). They found that teachers who utilised high levels of constructivist teaching practices tended to ask a significant number of questions, many of which were open-ended, and they balanced open-endedness by using closed questions to focus students' thinking as they carried out their investigations (Erodgan & Campbell, 2008).

In the 1970s, Rowe (1972) investigated the effect of wait time on the quality of classroom discourse and found that when primary science teachers used extended wait times of 3-5 seconds there was a positive impact on the level of students' involvement, the quality of their responses, and their capacity to make inferences supported by evidence. In addition, the teachers asked a greater variety and more probing questions, and demonstrated increased flexibility in the way they responded to students (Rowe, 1972). Tobin (1987) suggests that the increased silence created by the use of wait time gives teachers time to think and to formulate higher quality questions, while allowing students the space they need to construct more complex responses at a higher cognitive level.

Adjusting their Style of Interaction: What this Means for Teachers

Alexander (2006) found that teachers traditionally tend to use a basic repertoire of classroom talk and avoid using higher-order categories of questions because this affords them some security and ensures they retain control of classroom events and the content of the lesson, particularly where teachers have limited discipline content knowledge and PCK (Alexander, 2006; Koufetta-Menicou & Scaife, 2000; Rop, 2002). The literature clearly shows teaching that is limited to low level talk is unlikely to offer the kinds of cognitive challenge needed to develop students' capacity to reason.

To develop dialogue in classroom interactions, teachers need to consider how to structure questions that provoke thinking and how to make the most of students' responses. Alexander (2006) considers authentic questions, where the teacher has not pre-specified or implied a particular answer, are dialogic because they indicate the teacher's intention to engage with what students think and know. While it is important to consider carefully the kinds of questions asked of students, there is also a need for teachers to pay attention to the discourse moves they use when responding to their answers. Nystrand (1997) found that questions and discussion alone do not facilitate learning if students are not afforded the wait time to think about their answer. Collins (1982) also refers to a process of 'uptake', where teachers follow up on students' ideas by incorporating their responses into subsequent questions, which helps to build cumulative talk (Alexander, 2006).

Individual interactions can be chained into coherent lines of inquiry so that I-R-E patterns of discourse can be transformed into productive dialogue by supporting students to extend their contributions. Rather than evaluating students' responses to questions, teachers can build on I-R-E structures to develop chains of interactions, such as an I-R-F-R-F (Initiation-Response-Feedback-Response-Feedback) pattern of interaction (Mortimer & Scott, 2003). In this instance, the teacher's response encourages students to expand on and clarify their answers and to articulate their point of view. In this way, I-R-E patterns of discourse can be extended to support dialogic interaction and develop conversation threads and cumulative talk (Alexander, 2006).

In summary, the literature shows the quality of classroom talk depends on teachers orchestrating many factors including the length and patterns of interaction, the use of questioning and feedback, cognitive challenge, as well as the culture and organisation of the classroom. A further challenge for teachers is to match the communicative approach to the phase of scientific inquiry. Interactive and dialogic approaches are required in the Engage and Explore phases where the instructional purpose is to engage students in dialogue and explore their ideas about a topic. In the Explain phase, where the purpose is to accommodate students' views towards the scientific explanation, more authoritative approaches are required (Hackling, et al., 2010: Mortimer & Scott, 2003). This article reports on the ways that the teachers participating in this study adjusted their use of questioning and discourse moves so as to align their communicative approach with the phase of inquiry and facilitate the development of substantive talk in whole-class discussions. Examples from the transcripts of these substantive discussions are used to illustrate some of these practices.

Approach and Methods

The research design combined elements of participatory action research (Kemmis & McTaggart, 2000), design-based research collaboration (Schoenfeld, 2007) and Leach and Scott's (2002) approach to designing and evaluating science teaching sequences. Teachers were released from schools to participate in four days of collaborative research and professional learning where they worked with the researchers to develop new pedagogical strategies to scaffold classroom discourse. They designed ways of using these strategies to teach either *Primary Connections* or teacher-authored units in a manner that matched communicative approaches to instructional purposes and phases of inquiry. The teachers worked through two cycles of design, enactment, analysis and reflection, and redesign.

Professional Learning Model

The first two professional learning days (PL Day 1 and PL Day 2) were held consecutively. On PL Day 1, the teachers were introduced to educational principles relating to inquiry, instructional purposes and communicative approaches; and, they participated in workshops focusing on discourse strategies and approaches for managing classroom talk in inquiry-based science and analysing questioning techniques. On PL Day 2, the teachers collaborated in small groups to plan the delivery of a *Primary Connections* unit of work, which included planning whole-class discussions so that appropriate types of discourse were matched to the purpose of the lesson and the phase of inquiry. Following PL Days 1 and 2, the teachers returned to their respective schools to implement their planned unit of work with their class.

Approximately eight weeks later, the teachers attended PL Day 3 where they reflected on their implementation of the initial *Primary Connections* unit of work and on their capacity to use an appropriate communicative approach to scaffold student talk in whole-class discussions to suit lessons in the Engage and Explain phases. During this time of reflection, the teachers discussed what worked for them and what was problematic and two of the teachers also consented to sharing video footage of their practice. Using the video footage in this manner proved to be a powerful and impactful way to share productive discourse practices. The teachers were able to see and hear what different discourse strategies looked and sounded like, and to make connections to their own practice. Drawing on such a significant and relatable resource in this way also served to focus, contextualise and enrich the teachers' professional conversations. In the latter part of PL Day 3, the teachers collaborated once more to design the implementation of a second *Primary Connections* unit incorporating planned whole-class discussions, which they subsequently carried out with their classes.

When the teachers attended PL Day 4 about 10 weeks later, they participated in professional conversations where they reflected on the implementation of their second *Primary Connections* unit and on their use of communicative approaches in whole-class discussions. Several more teachers shared video footage of their practice, which facilitated further rich discussion and reflection on the ways that their management of classroom discourse had changed over the course of the professional learning intervention. Table 2 shows how the four days correlated to the design-based action research process.

Professional Learning Day	**Research and development and professional learning activities**
Day 1 Early June	Introduce a set of educational principles about inquiry, instructional purposes and communicative approaches. Half-day workshop on managing classroom discourse in inquiry-based science; and, analysing questioning techniques.
Day 2 Early June	Teams of three teachers collaborate to design approaches to teaching a *Primary Connections* unit, scaffolding discourse types to suit the instructional purposes of the Engage/Explore and Explain phases of inquiry.
Post Day 2	Teachers enact the design through teaching the *Primary Connections* unit.
Day 3 Late August	Teachers analyse and reflect on their implementation of their design and on their scaffolding of communicative approaches. Teachers work in teams of three to redesign their approaches in the context of a second *Primary Connections* unit.
Day 4 Mid November	Teachers analyse and reflect on their implementation of their design and on their scaffolding of communicative approaches. Teachers document resources for implementing a *Primary Connections* units and matching communicative approaches to instructional purposes of phases of inquiry.

Table 2: Relationship between the four professional learning days and the design-based action research process.

Participants

The professional development program was designed for confident teachers of primary science with good science content knowledge as it addressed sophisticated aspects of pedagogy relating to managing science classroom discourse. Following ethics approval being granted by the University and the education sector, employing authorities were asked to nominate teachers from their education systems who were confident science teachers who may be interested in participating in the program. These were approached by the research team and 12 teachers volunteered to participate. Informed consent was provided by school principals, teachers, parents and the children. Of the 12 teachers recruited for the study, five were approached to be subjects of case studies. While the data collection was undertaken for all five teachers, only three case studies were ultimately developed. The rationale for the selection of the three cases centred on the availability of a complete data set, as well as ensuring that the data represented a range of year levels (Kindergarten to Year 7) and school contexts; a mix of male and female teachers; and a range of teacher experience. Ultimately, one male and two female teachers were selected, and each case study teacher taught in quite different contexts and locations in Perth, Western Australia. For instance, Penny (pseudonym) taught a Year 6-7 class in a government school situated in the eastern foothills that was designated a lower than average socio-economic status. Holly (pseudonym) taught a Year 2-3 class in a government school located in a southern coastal suburb that was designated an average socio-economic status. While Ben (pseudonym) taught a Kindergarten-Year 1 class in an independent school located in an inner city suburb that was designated as higher than average socio-economic status.

Data Sources and Analysis

Extensive data were collected from several sources to build an account of each case study teachers' beliefs and knowledge about classroom discourse and of their teaching practice. This included: pre- and post-intervention teacher interviews; audio recordings of teacher plenary discussions; lesson observations, field notes, video recordings, and follow-up teacher interviews for five science lessons. A broadly interpretivist approach was taken to analyse and interpret the data with triangulation of data types and sources used to enhance the credibility and trustworthiness of research findings. Factors that influenced the teachers' capacity for effective implementation of communicative approaches were then identified from a cross-case analysis.

Field notes from lesson observations were used to: write brief lesson outlines; identify the phase of inquiry and instructional purpose of each science lesson; and, identify excerpts of whole-class substantive discussion for further analysis. A single camera, placed at the back of the classroom, was used to video lessons and a clear recording of the discourse was made via FM microphones that were linked to a receiver on the camera. Teachers wore an FM lapel microphone while a second microphone was placed in the middle of the classroom. Video recordings were digitised and imported into NVivo 8™ software for viewing, coding and analysis. A code book was developed to provide explicit naming and descriptions of codes. Two researchers compared their coding of transcripts to identify instances where different codes were assigned to the same event and to resolve these instances of unreliable coding. The most common sources of unreliability were: the lack of clarity of the code description; overlapping codes; or the need to establish a new code. Reliability improved when examples of instances and non-instances of the codes were included in the coding manual.

Segments of video recordings that showed parts of lessons involving whole-class substantive discussion, that is discussion which focused on clarifying and developing science understandings, were viewed and transcribed verbatim. The transcripts were then analysed to investigate how the teacher and students participated in discussion and a set of codes was developed that described: teacher questioning and discourse moves; the level of the teacher and student participation; and, the quality of the students' contributions to discussion.

The initial analysis of the transcripts highlighted how the teachers' asked different types of questions to initiate interactions or to maintain the momentum of the discussion (Smith, 2013). Subsequently, the analysis focused on the types and purposes of the teacher's initiating questions and they were coded as: *closed*, questions eliciting a limited number of responses; *open-ideas*, questions eliciting a range of ideas; *open-description*, questions eliciting description of an observation or event; *open-explanation~reason*, questions eliciting an explanation or a reason.

As well as examining how teachers used questioning in whole-class discussions, an important part of the analysis focused on identifying the kinds of discourse moves the teachers used to manage discussions. While some categories of teacher discourse moves were imposed on the data (e.g. *wait time* and *extended thinking time*), several categories emerged from the data as the analysis progressed (e.g. *turn taking*, *prompt and scaffold*, *teacher restate*).

The proportion of teacher/student talk was determined from the transcripts by completing a character count of the teacher and the student contributions to discussion. The character count was a consistent and simple quantitative measure that had no particular connection to the substantive meaning or content of an utterance. Additionally, the character count was used as a way to identify *elaborated utterances*, those contributions to discussion comprising 100 or more characters in the transcript, which provided a measure of student participation.

In order to analyse the quality of the students' contributions, their responses were coded according to their increasing complexity and abstraction. These codes were influenced by the Structure of the Observed Learning Outcome (SOLO) Taxonomy (Biggs, 2003) and ranged from descriptions of concrete experiences to explanations of more abstract scientific concepts. More specifically, the students' responses were coded for: *Description*, reporting of observable features or events, either one aspect (*unistructural*) or two or more aspects (*multistructural*); *Explanation*, providing an explanation of why something happened or how something will happen in the future; and, *Reasoning*, providing additional supporting reasons or justification for an explanation, which usually has recourse to empirical evidence or a science idea. The coding framework that was developed from this analysis is given below in Table 3.

Category	Definition of category
Teacher questions	
Closed	Elicits a limited number of response options.
Open - ideas	Elicits ideas. Includes 'What do you think?'
Open - description	Elicits a description. Includes 'What do you see?' 'What happened?'
Open-explanation/reason	Elicits an explanation (why something is so) or a reason to justify a claim (how do you know).
Teacher discourse moves	
Acknowledge only	Teacher just acknowledges a student response with no further interaction.
Asks a question to initiate discussion	Teacher asks an open question to initiate discussion.
Asks for other ideas	Teacher asks for other (different) ideas.
Checks for consensus	Teacher asks the class to indicate who agrees with an idea.
Directed question	Teacher directs a question to a named student.
Elaborate	Teacher asks for elaboration of a response (to say more about it).
Evaluate	Teacher indicates whether an answer is correct or incorrect.
Extended Thinking Time	Teacher extends thinking time using strategies other than Wait Time, e.g. Think-Pair-Share, Thinking Time, writing a draft, other.
Ignore	Teacher ignores a student response.
Moves on	Teacher asks a question which changes the focus of discussion.
Park a question or response	Teacher acknowledges a student's question or response that is tangential to the focus of the discussion, indicating that it will be attended to subsequently.

Prompt and scaffold	Teacher provides cues before or after a question to prompt/scaffold student's responses.
Recast the question	Teacher does not receive an answer or receives an unsuitable response and rephrases the question.
Refocus	Teacher summarises to consolidate and refocus the discussion.
Reframe	Teacher rephrases a student answer to improve expression.
Reframe scientifically	Teacher rephrases student answer to correct science.
Restate/clarify	Teacher asks a student to restate so audible to class or to clarify what was said.
Teacher restates	Teacher repeats or restates what has been said.
Teacher uptake	Teacher asks a follow-up question that includes (builds on) part of a previous answer.
Turn taking (teacher nominated)	Teacher nominates one student after another to respond without calling for elaboration or explanation of their ideas.
Quality of student talk	
Description	Student provides descriptions of objects or events currently being observed or previously experienced. Coded as *unistructural* when one aspect is reported and *multistructural* when two or more aspects are reported.
Explanation	Student provides an explanation of how or why it is so and may include explanations of what is likely to happen next.
Reasoning	Student provides reasoning. Includes some scientific reason to justify an explanation.
Elaborated utterance	Student utterance is greater than 100 characters of transcript.

Table 3: Codes developed to analyse classroom discourse.

As the development of each case study progressed, key findings and assertions were developed regarding individual teacher's beliefs, knowledge and practice as well as the students' participation and the quality of their talk. Generating key findings and assertions in this manner helped to reveal the way in which the teachers' and the students' participation in whole-class discussions developed over the course of the professional learning intervention. This also facilitated a cross-case analysis where the assertions from each case study were analysed collectively and a set of themes was developed based on teachers' beliefs, knowledge and practice relating to: effective science teaching; developing a supportive classroom environment for talk; the use of questioning and teacher discourse moves and adjusting the communicative approach in science lessons.

Results and Discussion

As the analysis progressed, themes emerged relating to teachers' questioning, discourse moves, and responses to the professional learning program. These themes are developed in the following sections.

Teachers' Practice: Asking a Variety of Questions

In the Engage phase of inquiry, the data showed that each of the teachers typically asked *open-ideas* questions to 'open up' (Erdogan & Campbell, 2008) a discussion in order to find out what their students knew about a topic. In the later parts of the professional learning intervention, the teachers began to ask some *open-description* and *open-explanation~reason* questions when they wanted to probe the students' thinking or get them to elaborate on their ideas. When discussing the students' investigations in the Explain phase, the data showed that the teachers tended to ask *open-description* questions to elicit the students' observations of a phenomenon or their descriptions of what had happened. They asked *open- explanation~reason* questions to elicit the students' explanations about why something had occurred or a reason which justified a claim about how it may have happened. In addition, when planning new investigations, the teachers asked *open-ideas* questions to elicit the students' predictions about what might happen or what they might do next to find out more about a particular phenomenon. These question sequences supported and scaffolded students' inquiries.

The teachers mostly asked *closed* questions when they wanted to: clarify a student response; refocus the discussion by drawing together a range of ideas; or manage the flow of the discussion. They asked significantly more *closed* questions in the Explain phase when they wanted to shape the discussion so as to make the science ideas explicit and the communicative approach changed from being dialogic to more authoritative (Mortimer & Scott, 2003).

Each of the case study teachers began to use the range of questions described above to probe their students' ideas and to help them to think more deeply about their investigations. This probing pattern of interaction became progressively more apparent in discussions during the Explain phase but, as stated previously, it was also evident in some Engage lessons when the teacher wanted to explore the students' initial understandings more carefully. When the probing sequence was utilised, the teacher typically asked *open-ideas* (and some *open-description*) questions to initiate the discussion about a phenomenon but then followed up with *open-description* questions and then *open-explanation~reason* questions to prompt the students to think about why something had happened. In this sequence, the teachers would also ask *closed* questions to support the students to reach an explanation, thus shaping the discussion and narrowing the range of ideas for the students to focus on. This result is consistent with the research which found that teachers using constructivist teaching practices asked more open-ended questions than any other type, and they used closed questions to shape their students' thinking during the process of inquiry (Erodgan & Campbell, 2008).

A good example of the probing sequence is evident in Penny's final Explain lesson (Lesson 5) when she led students to answer an *open-explanation~reason* question about the importance of heat in the germination process by asking *open-description* and *closed* questions. In this lesson, Penny wanted the students to describe how their seeds had sprouted and she persistently adapted her use of questioning and discourse moves to guide them to articulate explanations for the way their seeds had developed and to reason about the conditions that facilitated the germination process. An excerpt from the transcript of Lesson 5 is given in Table 4 below.

Turn	Utterances	Coding
1.	T (Teacher): OK, Michelle, your group. Did all your different groups of seed sprout on the same day?	Initiating question, closed question.
2.	**Michelle: No, the wheat sprouted first and then the others just sprouted all like together or something.**	Multistructural description.
3.	T: So about the same time? What day did the wheat sprout? [Wait Time1] Where is it on your sheet? What day did your wheat sprout?	Clarify, closed question. Open-description question. Wait time 1.
4.	**Michelle: I think it sprouted like yesterday and the others sprouted today.**	Multistructural description.
5.	T: OK, so your wheat really sprouted, you reckon, Day 6.	Reframe.
6.	**Michelle: Yep.**	
7.	T: You had wheat sprouting first, what day did your wheat sprout?	Closed-description question.
8.	**S1** (Student 1)**: About Day 4.**	Unistructural description.
9.	T: Day 4, a bit before. So why do you think your wheat took a little bit longer than this group's maybe?	Restate. Open-explanation~reason question.

10.	**Michelle: Maybe we didn't water it enough or as much and it wasn't as close to the window.**	Explanation.
11.	T: OK. So why would it have to be closer to the window to make a difference?	Teacher uptake, open-explanation~reason question.
12.	**Michelle: To get more sunlight.**	Reasoning.
13.	T: To get more sunlight. Anything else you want to share about why you think that might have happened and why the other seeds haven't sprouted or took so long to sprout? Jason?	Teacher restate. Elaborate. Open-explanation~reason question.
14.	**Jason: I think all the seeds sprouted at different times because of the heat.**	Reasoning.
15.	T: Because of the heat. The heat within the classroom? So why do you think the heat would have made a difference to the seeds?	Teacher restate. Clarify. Open-explanation~reason question.
16.	**Jason: Because you need heat for things to grow.**	Reasoning.
17.	T: You need heat for things to grow, well done. Walt?	Teacher restate. Evaluate. Asks another student for his/her ideas.
18.	**Walt: Well you… maybe its um.. temperature you know how it's cold and some seeds may need heat to grow.**	Reasoning.
19.	T: Definitely. So they need the heat and a certain temperature.	Evaluate. Reframes.
20.	**S2: Others need hot and warm.**	Reasoning.
21	T: So different types of seeds need different conditions so different temperatures, some like a warm temperature, some would like it a little bit cooler. So I think we had a discussion, was it last time we discussed or when we talked about apples, when we talked about growing apples and we said they needed like a cooler temperature to grow those seeds, didn't they? So we'd see if we put an apple seed we'd have the same joy. So maybe our classroom has been quite warm, the conditions have been right do you think for these seeds? Christine?	Refocus. Prompt and scaffold. Asks another student for his/her ideas.
22.	**Christine: With the millet seed, I reckon that they're kind of a cold kinda thing because they haven't grown that much.**	Reasoning.
23.	T: OK, so you think the millet has taken a time to sprout because it prefers the cold.	Reframe.

Table 4: Lesson 5 - the teacher probed the students' ideas to elicit explanations and scientific reasons.

In this excerpt (Table 4), Penny (T) asked Michelle about the seeds her group had planted (turn 1) and she established that their wheat seeds had sprouted first on Day 6 (turn 5). Penny compared these results with those of another group (turn 7) whose wheat seeds had sprouted on Day 4 and she asked Michelle why her group's wheat took longer to sprout (turn 9). Michelle thought that perhaps her group had not watered their seeds enough and that they were not as close to the window. Penny picked up on her idea and asked why she thought putting the seeds closer to the window would make a difference (turn 11). Michelle explained that it would give the seeds more sunlight (turn 12). Penny asked further *open-explanation~reason* questions (turn 13; turn 15) and she elicited additional explanations and reasons (turns 14 and 16) about the importance of heat in the germination process. Subsequently, Penny summarised the students' explanations (turn 21) and the focus of the conversation turned to the conditions needed for the millet seeds to grow (turn 22).

In Lesson 5, Penny developed the interaction by asking *open-description* questions and then a succession of *open-explanation~reason* questions to elicit the students' explanations and reasons. Additionally, she used discourse moves to support the students to articulate their ideas (*clarify, wait time, reframe, teacher restate, elaborate)* and to reinforce particular ideas *(teacher uptake, teacher restate, evaluate, refocus, prompt and scaffold, reframe*). By working the discussion in this way, Penny facilitated the development of cumulative talk (Alexander, 2006).

A key purpose of teacher questioning is to promote students' learning. Koufetta-Menicou and Scaife (2000) argue that teachers cannot assume their teaching has been effective in developing higher-level thinking unless they ask higher-order questions. They consider higher-order questions are more cognitively demanding as they require students to make and justify judgements, arguments or explanations, develop hypotheses, or make predictions and draw conclusions, all of which are important to scientific literacy (Osborne et al., 2004). While this might be a useful way to help teachers to think more carefully about their use of questioning, it is also important to pay attention to how a series of different types of questions can work in combination to achieve higher-level thinking. For example, *open-description* and *closed* questions might appear to fit a lower-order classification but they are very important to the probing sequence, which calls for students to develop explanations and reasons for their findings based on their observations and experiences. A visual representation of the probing sequence the teachers used to support their students to develop explanations and reasons is given below in Figure 1. It illustrates how the teachers might ask a series of *open-ideas*, *open-description* and *open-explanation~reason* questions to support students to articulate their observations and develop explanations and scientific reasons for them.

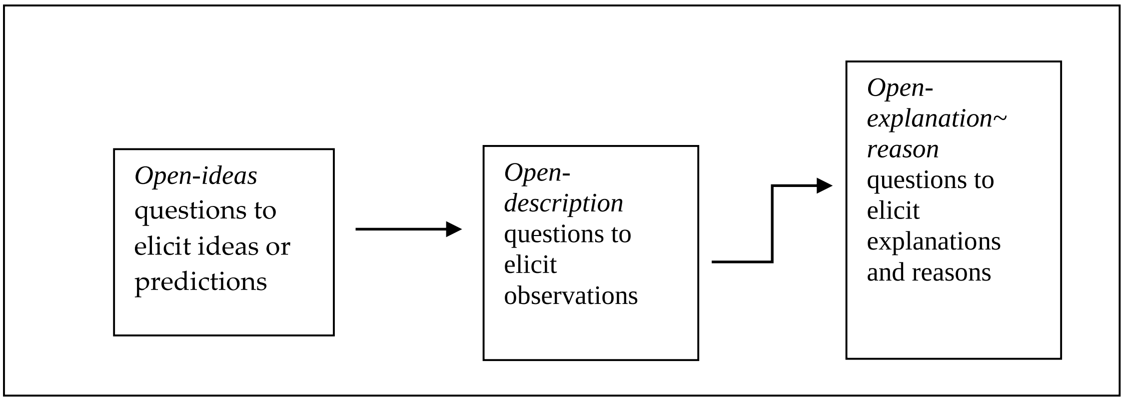

Figure 1: The probing sequence of questions teachers used to support students to develop explanations and reasons.

Teachers' Practice: Developing a Repertoire of Discourse Moves

While it is important for teachers to pay attention to how they use questions in whole-class substantive discussions, Tytler and Aranda (2015) argue that it is also important that they pay attention to students' answers and what they do with those answers. The initial interview data showed the teachers believed that discussion was an effective tool for fostering students' participation, sharing ideas, and ascertaining their understandings of science; and that this requires a positive and supportive classroom culture. Thinking about discussion in this way gives emphasis to the inclusive and democratic aspects of classroom talk and this was clearly reflected in Holly's initial Engage lesson (Lesson 1) when she focused on ensuring all the students had their say. In Table 5 below, an excerpt from the transcript of Lesson 1 shows how Holly tried to maximise student involvement in the discussion by nominating several students in succession to respond to each of her questions, without repeating the question. This was the introductory lesson in the Engage phase of a new topic to do with sounds.

Turn	Utterances	Coding
1.	T: What was the sound like? Can you describe what the sound was like? Who'd like to do that? Tara?	Initiating question, open–description question.
2.	**Tara: Um.. like a rustle, rustle sound.**	
3.	T: Rustle, rustle. Alison?	Teacher restate. Directed question.
4.	**Alison: Like a... kind of like a rubbing something hard sound.**	
5.	T: Rubbing sound. Lucy?	Teacher restate. Directed question.
6.	**Lucy: Um.. kind of like a scratching sound.**	
7.	T: A scratching sound. John?	Teacher restate. Directed question.
8.	**John: Shaking sound.**	
9.	T: Shaking sound. [Points to another student]	Teacher restate. Directed question.
10.	**S: A rattle sound.**	
11.	T: A rattle sound. OK.	Teacher restate.

Table 5: Lesson 1 - an example of teacher nominated turns, described as turn taking.

In this excerpt (Table 5), Holly (T) asked an initiating question to elicit the students' descriptions about the sound they had heard and she nominated Tara to answer (turn 1). Tara described a rustling sound (turn 2) and Holly restated her response and then nominated another student to give their ideas (turn 3). The coding of this discussion revealed that Holly frequently nominated a student to answer her question, restated what they had said and, without further interaction, moved on to nominate another student for their ideas (turns 3, 5, 7, 9 and 11). In this study, when a teacher repeatedly responded in this way the pattern of interaction that evolved was described as *turn taking*.

Turn taking was comprised of Initiation-Response-Restate (I-R-R), where the teacher asked a question (Initiation), listened to a student's answer (Response), and restated (Restate) their response. While the I-R-R response looks similar to other three-turn structures such as the I-R-E (Mehan, 1979) and the I-R-F (Sinclair & Coulthard, 1975) described in the literature, it is in fact less productive. The I-R-E pattern of interaction represents a teacher-student exchange in which the teacher assesses the correctness of the response (Evaluate), thus providing some limited form of feedback. The *turn taking* or I-R-R pattern of interaction seen in Holly's first discussion, produced brief teacher-student exchanges where the students gave simple responses that the teacher merely restated. While this form of interaction served to quickly elicit many of the students' ideas, it did not provide them with any feedback and, like most triadic dialogue served to shut down the interaction and the chance for students to talk through their ideas. Lemke (1990) maintains that when this happens, teachers miss an opportunity to gauge students' real understandings or misunderstandings about a topic. However, given the opportunity to view her lesson video as well as other video examples of effective practice, Holly quickly changed the way that she interacted with her students. Thus, while it is important for teachers to foster the inclusive and democratic aspects of classroom talk, it is also important that they recognise what substantive discussion is, what the benefits are for their students, and how they can achieve this in their practice.

Ultimately, the teachers in this study developed a repertoire of discourse moves that they used during whole-class discussions. Moreover, they tended to marry particular types of questions and discourse moves, depending on the discourse strategy they wished to employ and the communicative approach required for the instructional focus of the lesson and phase of investigation. In the Engage phase, when they wished to initiate discussion about a new topic, the teachers utilised an Interactive-Dialogic communicative approach whereby they asked predominantly *open-ideas* and *open-description* questions, and fewer *open-explanation~reason* questions. In addition, they combined an increasingly sophisticated range of discourse moves to initiate and build the talk, to explore and develop students' ideas and their use of scientific language, and to manage the discourse.

The teachers initiated and built up the interaction by:

- supporting students to articulate and clarify their ideas (*teacher restate, clarify*);
- building on students' ideas (*clarify*, *teacher uptake*);
- maximising the interaction with individual students (*elaborate, teacher restate, teacher uptake*); and,
- endorsing students' responses (*evaluate, acknowledge only*).

The teachers investigated and developed the students' ideas by:

- exploring (*teacher uptake*, *wait time*, *extended thinking time*, *prompt and scaffold; or teacher uptake*, *clarify,* and *elaborate*) and probing their ideas (*directed question*, *teacher restate*, *teacher uptake*, *reframe*, and *evaluate*);
- maintaining a line of questioning (*acknowledge only*, *recast the question*, *asks for other ideas*);
- giving them time to think (*wait time, extended thinking time*); and,
- summarising their ideas (*refocus).*

The teachers developed the students' ideas and use of language by:

- supporting their use of appropriate terminology and rephrasing their ideas (*reframe*); and,
- modelling appropriate scientific language (*reframe scientifically*).

Additionally, the teachers managed the discourse by:

- orchestrating the flow of the discussion (*directed question, parking, acknowledge only, moves on*).

In Explain lessons, the teachers utilised an Interactive-Dialogic communicative approach when they wanted students to review their observations and results from the activities carried out in the Engage and Explore phases of investigation. They asked *open-ideas* and *open-description* questions and they used discourse moves to initiate and build the interaction by:

- supporting students to articulate their ideas (*clarify*, *prompt and scaffold*, *wait time* and *teacher uptake;* or *teacher restate, clarify,* and *elaborate*); and,
- maximising the interaction and helping students to link their ideas to the problem (*teacher restate*, *clarify*, *teacher uptake*, *extended thinking time*, *checks for consensus*, *evaluate*, and *refocus*).

When the teachers wanted students to develop explanations and reasons for their results they adjusted their communicative approach to a more Interactive-Authoritative style where they asked more *open-description, closed* and *open-explanation~reason* questions, and they used discourse moves to:

- develop students' ideas and use of language (*prompt and scaffold, extended thinking time,* and *refocus*);
- give students time to think (*wait time* and *extended thinking time*);
- reshape and accumulate students' ideas (*clarify*, *reframe*, *refocus*); and,

- develop cumulative talk and summarise students' ideas (*refocus*).

In addition, the teachers emphasised scientific ideas by:

- reinforcing and making key ideas explicit (*teacher uptake, teacher restate, evaluate, refocus, prompt and scaffold, reframe*); and,
- explaining and emphasising key understandings (*elaborate, teacher restates, clarifies, teacher uptake, evaluate, reframe, prompt and scaffold, reframe scientifically*).

These data show that the teachers had developed skills of matching their discourse strategies to the instructional purposes of the phases of inquiry. During the Engage phase the teachers used an Interactive-Dialogic communicative approach to achieve the instructional purpose of initiating talk and exploring students' ideas. The instructional purposes of the Explain phase are to: (1) review observations and findings from the students' investigations; and then, (2) develop scientific explanations for those observations. The teachers used an Interactive-Dialogic communicative approach to achieve the first purpose and then reached a turning point in the lesson (Scott, 2008) where they switched to an Interactive-Authoritative approach to achieve the second instructional purpose.

The teachers also focused on incorporating *wait time* into their discourse practice. At the start of the intervention, Ben and Holly had understood that teachers need to give students the time to think during discussions and Penny believed that she was effective in using *wait time*. However, the video data from Lesson 1 showed that neither Holly nor Penny had used *wait time* in their practice. At the midpoint of the professional learning intervention, Ben reported that he had focused on using *wait time* and his consistent use of *wait time* and *extended thinking time* was increasingly evident in the video footage in all five of his lessons. Similarly, Penny reported that she had used *wait time* and *extended thinking time* successfully and this was more evident in her practice in the Explain lessons (Lessons 3 and 5). Holly also reported that she had used *wait time* and, while she had begun to use some *extended thinking time*, there was no evidence in the video footage that she had used *wait time* in her discourse practice.

By making room for the students to participate in the discussion and encouraging them to articulate, elaborate on and clarify their ideas, the teachers in this study supported their students to be accountable for their thinking. In addition, they orchestrated the conversation so that the students' contributions formed cohesive chains of interaction much like the I-R-F-R-F (Initiation-Response-Feedback-Response-Feedback) pattern of interaction described by Mortimer and Scott (2003). The literature shows that this responsive way of working and managing the discourse is typical of classrooms that generate productive interactions in whole-class discussions (Tytler & Aranda, 2015). For Penny and Holly, this marked a significant change to their beliefs, knowledge and practice and is evidence that they had responded positively to the feedback they had gained from working with their students and from their engagement with the professional learning process which involved viewing video of other teachers' practice.

It was evident from the analysis of their class discussions that the case study teachers' use of discourse moves became increasingly sophisticated and complex. The codes generated from the analysis of the transcripts have highlighted a range of possible discourse moves that teachers can draw on to orchestrate the talk in their classrooms. Table 6 shows how these codes can be loosely categorised according to their purpose - to initiate talk, to build the talk, or to close off the talk and move the discussion on to a new theme. As stated previously, the discourse moves can be used in conjunction with one another to achieve a range of purposes and some discourse moves can be categorised in multiple ways. For example, while *wait time* and *extended thinking time* can be used to help initiate interaction, they are equally useful in building talk. Similarly, while a *turn taking* pattern of interaction might serve to close off substantive discussion, it is still useful for eliciting many ideas at once.

Teacher discourse moves used to initiate talk	
Asks an open question	Teacher asks an open question to initiate discussion.
Directed question	Teacher directs a question to a named student.
Turn taking (teacher nominated)	Teacher nominates one student after another to respond without calling for elaboration or explanation of their ideas.
Wait Time	Teacher pauses for greater than "one and two" (WAIT time) after asking a question (WT1) or after a student's response (WT2).
Extended Thinking Time	Teacher extends thinking time using strategies other than Wait Time, e.g. Think-Pair-Share, Thinking Time, writing a draft, other.
Recast the question	Teacher does not receive an answer or receives an unsuitable response and rephrases the question.
Teacher discourse moves used to build the talk	
Teacher restates	Teacher repeats or restates what has been said to give further time for it to be considered.
Restate/clarify	Teacher asks a student to restate so audible to class or to clarify what was said.
Reframe	Teacher rephrases a student answer to improve expression.
Reframe scientifically	Teacher rephrases student answer to correct science.
Elaborate	Teacher asks for elaboration of a response (to say more about it).
Prompt and scaffold	Teacher provides cues before or after a question to prompt/scaffold student's responses.
Refocus	Teacher summarises to consolidate and refocus the discussion.
Teacher uptake	Teacher asks a follow-up question that includes (builds on) part of a previous answer.
Teacher discourse moves used to close off the talk and to move on	
Park a question or response	Teacher acknowledges a student's question or response that is tangential to the focus of the discussion, indicating that it will be attended to subsequently.
Ignore	Teacher ignores a student response.
Acknowledge only	Teacher just acknowledges a student response with no further interaction.
Evaluate	Teacher indicates whether an answer is correct or incorrect.
Checks for consensus	Teacher asks the class to indicate who agrees with an idea.
Asks for other ideas	Teacher asks for other (different) ideas.
Moves on	Teacher asks a question which changes the focus of discussion.

Table 6: Categorising teacher discourse moves according to their purpose.

Clearly, teachers who are armed with a good repertoire of discourse moves as well as the knowledge of how to orchestrate discussion to achieve cumulative talk (Alexander, 2006) are more likely to achieve the kind of whole-class interaction needed to engage students in substantive discourse or 'talking for thinking'. In this study, the data showed that when the teachers aligned their communicative approach and use of questioning and discourse moves with the purposes of the Engage/Explore and Explain lessons, they facilitated their students' participation in discussion. Consequently, the students were able to provide increasingly elaborated responses and they were able to build on each other's ideas to generate cumulative talk. Additionally, the data showed the quality of the students' contributions to discussion increased and they were able to give progressively more complex descriptions, explanations and reasons. As Chin (2007) has noted, it is the use of open questions requiring extended responses that engages students in these types of higher order thinking.

A visual representation of some of the discourse moves teachers might draw on to respond to students' ideas is given below in Figure 2. It shows how a teacher might ask an initiating question and then use *wait time* to give students time to think before nominating someone to respond. Once a student has responded, the teacher can select from a range of discourse moves to:

- provide further wait time, thus allowing time for the class to consider the student's response;
- park a tangential response;
- ignore the response and allow the student's idea to fade away;
- acknowledge the response without further interaction;
- restate the response to give further time for it to be considered;
- reframe the response to improve the way that the response has been expressed;
- evaluate the response by indicating whether it is correct or incorrect;
- ask the student to clarify what they have said;
- ask the student to elaborate on their response;
- draw on the response to formulate a new question; or
- ask other students for their ideas.

Plainly, some discourse moves serve to close off the interaction (ignore, parking, acknowledge only, and evaluate) and others open up the discourse and invite further interaction (wait time, clarify, elaborate, and asks for other ideas). Once a particular chain of interaction has achieved its purpose or has been exhausted, the teacher can go on to ask another initiating question and to draw on other discourse moves to build and shape the discussion. To manage substantive discourse within science lessons requires the teacher to monitor the progress of the discussion in relation to the instructional purpose, make decisions about closing down potentially unproductive conversation threads or opening up, extending and probing ideas further seeking explanations and evidence to support them. Given the wide range of question types and discourse moves potentially available to a teacher and the constant decision making needed 'in the moment', it is not surprising that many teachers experience difficulty in orchestrating productive discussions (Harris et al., 2012).

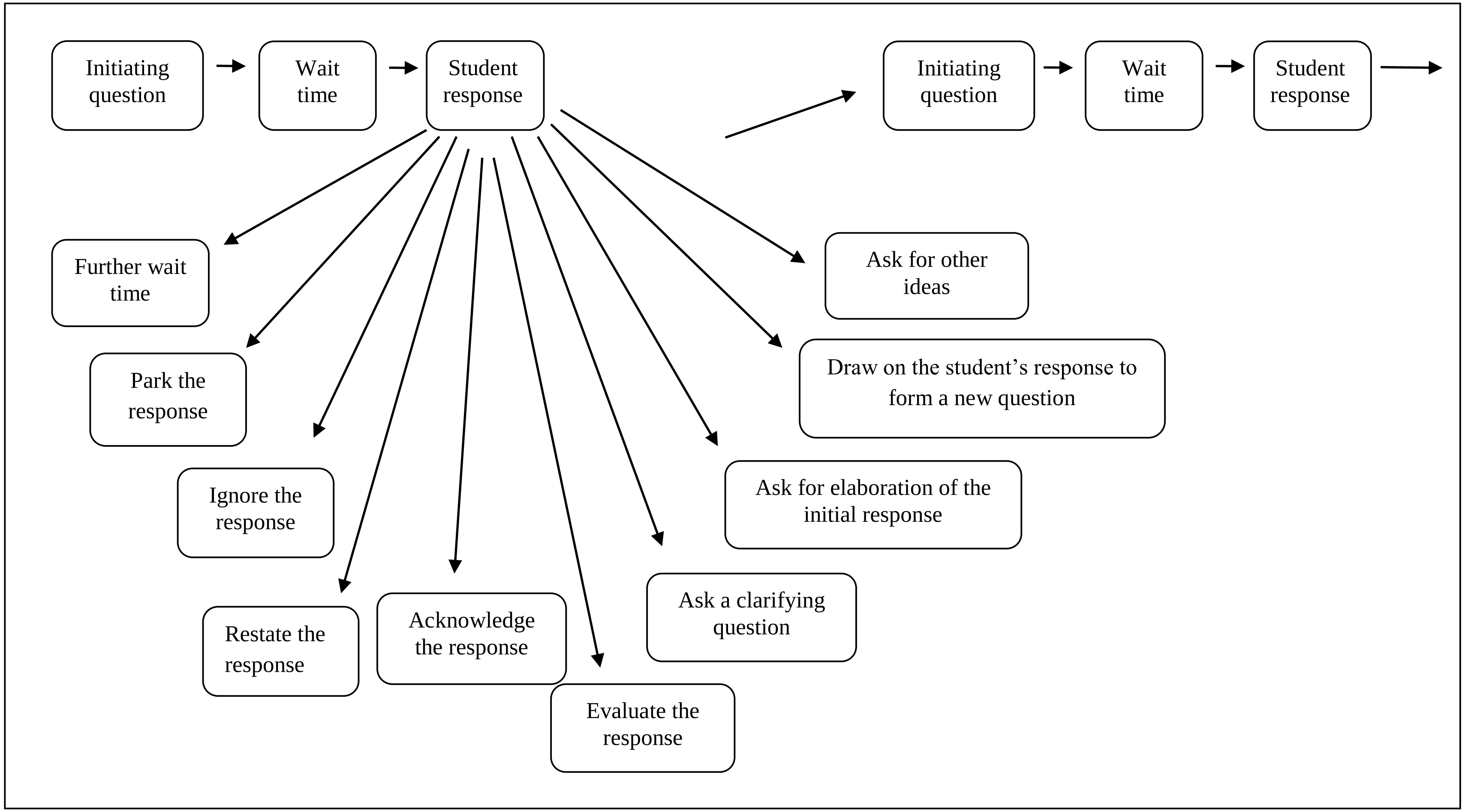

Figure 2: The complexities of discourse interactions.

Supporting Teachers to Achieve Productive Discourse

The teachers' engagement with professional learning enabled them to successfully develop their capacity to scaffold productive discourse in their primary science classrooms and there were several features of the professional learning that facilitated this. The teachers were offered a range of learning events. They participated in workshops that helped them to increase their knowledge about the principles of effective classroom discourse and good discussion pedagogy. They engaged in extended professional conversations that helped them to: develop shared understandings and a common language about classroom discourse; build their pedagogical content knowledge about the importance of student talk in helping students to think about and extend their understandings of science ideas; and, understand how teacher questioning and responding to students impacts on the development of students' thinking (Hackling et al., 2010). In addition, the teachers shared video footage and shared transcripts of their class discussions that enabled them to view examples of good discussion pedagogy and to consider how different types of questions and ways of responding to students' answers supported sustained conversation (Hackling et al., 2011). As a result of sharing their practice, the teachers developed openness and they seemed to work as a professional learning community (Hackling et al., 2011).

Another important aspect of the professional learning experience was the opportunity for teachers to obtain immediate feedback about their practice. As they began to develop the culture for talk in their classrooms and to implement the *Primary Connections* units they had planned, the teachers gained valuable feedback about their practice from the extent of the students' engagement and the quantity and quality of their contributions to discussion (Hackling et al., 2011). Furthermore, when the teachers viewed the video footage and participated in follow-up interviews about each lesson, they were able to reflect more deeply on the effectiveness of their practice. The video footage of their teaching provided authentic and impactful feedback on their questioning and discourse moves. As previous research has shown (e.g., Zhang, Lundeberg, Koehler & Eberhardt (2011) video has particular affordances as a source of feedback on practice: teachers can view the entire footage or select critical incidents for replay and more detailed analysis; gain new perspectives and insights; and notice salient aspects of practice that are momentary and fleeting. Viewing colleagues video within a supportive professional learning community had additional benefits including: noticing a wider range of salient features of practice and reasoning about their significance thus building professional vision (Sherin & van Es, 2009); and, seeing what strategies were used by other teachers to manage discourse and increasing their awareness of a wider range of discourse moves.

At the start of the professional learning intervention, some of the teachers asked appropriate questions to elicit the students' ideas; however, they used a limited range of discourse moves. This meant that they missed the opportunity to explore the students' ideas and they prevented the students from giving elaborated responses, which inhibited the development of cumulative talk. Over the course of the professional learning intervention, the teachers developed their capacity to adjust their questioning to fit the instructional focus of a lesson and they became more adept at using a sequence of questions to elicit, explore and probe their students' ideas and to help them develop explanations and reasons for their findings. The teachers also extended the repertoire of discourse moves they used to support their questioning and to differentiate their management of class discussions. Ultimately, each of the case study teachers also demonstrated an increased capacity to adjust their use of questioning and discourse moves so that their communicative approach matched the instructional focus of the lesson and phase of investigation.

Conclusions and Implications

This research has shown that if teachers are to increase their capacity to develop effective classroom discourse in science they need to know what substantive discourse is, what it looks like in the context of whole-class discussions, and how to use questioning and discourse moves to generate and manage such talk. They also need to know how to match their communicative approach to the instructional focus of the lesson and the phase of inquiry so as to progress the discourse from simply engaging and exploring the students' ideas to supporting them to develop clear explanations and scientific reasons for their findings. Considering discussion in this way places a greater emphasis on using classroom talk as a tool for deeper thinking and on the role of the teacher in developing and sustaining talking for thinking, meaning making and reasoning. The detailed analysis and coding of transcripts that were undertaken in this study revealed how teachers combine questioning and discourse moves to build productive classroom discussions. The teachers developed questioning sequences that progressed from *open-ideas* questions when formulating predictions to *open description* questions when eliciting observations and then to *open explanation-reason* questions when eliciting explanations and reasons for the observations made. The teachers also used different sets of discourse moves that were suited to: exploring and developing students' ideas; developing students' scientific language; developing, clarifying and extending explanations and reasoning; and, closing off conversation threads.

The research has also shown that professional learning providers need to design programs that offer teachers multiple opportunities to develop their pedagogical understandings and practice. In this case, an action research approach was used and the teachers were able to collaborate to design and plan units of work which they then implemented in their classrooms. Subsequently, they were able to view, reflect on and gain feedback about their own discourse practice and to examine how their interaction supported students' deeper thinking and reasoning. The video footage that was captured of teacher practice proved to be a vital tool for professional learning. It not only provided the means for teachers to view and gain feedback about their own practice but it also facilitated the sharing of practice and provided a rich contextual stimulus for professional conversations, thus supporting the teachers to learn from one another.

The set of codes that were developed to describe such teacher-student interactions will serve as a valuable tool of analysis for future researchers. Further studies might investigate how changes to the teachers' discourse practice were sustained over time and what impact their improved practice had on students' learning outcomes. Furthermore, it would be useful to understand how the improvements seen in whole-class discourse translate to the student-to-student interactions in both whole-class and small group discussions and whether students are able to generate substantive talk. The strong and positive impact of viewing one's own practice and sharing practice through the medium of video observed in this study suggests that the use of video should be used more widely in professional learning programs.

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